TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

MECHANICAL ENGINEERS.

VOL. III.

1882.

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OFFICERS

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

1882–1883.

PRESIDENT:

E. D. LEAVITT, Jr.,
Cambridgeport, Mass.

VICE-PRESIDENTS:

Chas. E. Emery,	New York City,	Term expires Nov. 1, 1883.
Wm. P. Trowbridge,	New York City,	" " " "
S. B. Whiting,	Pottsville, Pa.,	" " " "
John Fritz,	Bethlehem, Pa.,	" " Nov. 1, 1884.
William Metcalf,	Pittsburgh, Pa.,	" " " "
Henry Morton,	Hoboken, N. J.,	" " " "

MANAGERS:

George Fisher,	St. Louis, Mo.,	Term expires Nov. 1, 1883.
J. F. Holloway,	Cleveland, Ohio,	" " " "
John E. Sweet,	Syracuse, N. Y.,	" " " "
George H. Babcock,	New York City,	" " Nov. 1, 1884.
S. W. Robinson,	Columbus, Ohio,	" " " "
Allan Stirling,	New York City,	" " " "
Robert W. Hunt,	Troy, N. Y.,	" " Nov. 1, 1885.
Charles T. Porter,	New York City,	" " " "
C. J. H. Woodbury,	Boston, Mass.,	" " " "

TREASURER:

Charles W. Copeland, 24 Park Place, New York City.

SECRETARY:

F. R. Hutton, 15 Cortlandt St., and 50th St. and 4th Ave., New York City.

STANDING COMMITTEES.

ON FINANCE:

WM. P. TROWBRIDGE, D. S. HINES,
WM. H. WILEY, L. B. MOORE,
GEO. H. BABCOCK.

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ON REGULAR MEETINGS:

WASHINGTON JONES, COLEMAN SELLERS,
CHAS. E. EMERY, MATTHIAS N. FORNEY,
HENRY MORTON, J. F. HOLLOWAY,
WM. LEE CHURCH.

ON ROOMS AND CONVERSAZIONE:

S. B. WHITING, THOMAS WHITESIDE RAE,
ROBERT GRIMSHAW, HORACE B. MILLER,
W. BARNET LE VAN, C. J. H. WOODBURY.

AMENDED.

[*November 19th*, 1889—*November 17th*, 1891.]

RULES

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

[*Adopted November 5th*, 1884.]

OBJECTS.

ART. 1. The objects of the AMERICAN SOCIETY OF MECHANICAL ENGINEERS are to promote the Arts and Sciences connected with Engineering and Mechanical Construction, by means of meetings for social intercourse and the reading and discussion of professional papers, and to circulate, by means of publication among its members, the information thus obtained.

MEMBERSHIP.

ART. 2. The Society shall consist of Members, Honorary Members, Associates and Juniors.

ART. 3. Mechanical, Civil, Military, Mining, Metallurgical and Naval Engineers and Architects may be candidates for membership in this Society.

ART. 4. To be eligible as a *Member*, the candidate must have been so connected with some of the above-specified professions as to be considered, in the opinion of the Council, competent to take charge of work in his department, either as a designer or constructor, or else he must have been connected with the same as a teacher.

ART. 5. *Honorary Members*, not exceeding twenty-five in number, may be elected. They must be persons of acknowledged professional eminence who have virtually retired from practice.

ART. 6. To be eligible as an *Associate*, the candidate must have such a knowledge of or connection with applied science as qualifies him, in the opinion of the Council, to co-operate with engineers in the advancement of professional knowledge.

ART. 7. To be eligible as a *Junior*, the candidate must have been in the practice of engineering for at least two years, or he must be a graduate of an engineering school.

The term "Junior" applies to the professional experience, and not to the age of the candidate. Juniors may become eligible to membership.

ART. 8. All Members and Associates shall be equally entitled to the privileges of membership. Honorary Members and Juniors shall not be entitled to vote nor to be members of the Council.

ELECTION OF MEMBERS.

ART. 9. Every candidate for admission to the Society, excepting candidates for honorary membership, must be proposed by at least three members, or members and associates, to whom he must be personally known, and he must be seconded by two others. The proposal must be accompanied by a statement in writing by the candidate of the grounds of his application for election, including an account of his professional experience, and an agreement that he will conform to the requirements of membership if elected.

ART. 10. All such applications and proposals must be received and acted upon by the Council at least thirty days before a regular meeting, when the Secretary shall at once mail to each member and associate, in the form of a letter ballot, the names of candidates recommended by the Council for election.

ART. 11. Any member or associate entitled to vote may erase the name of any candidate, and may, at his option, return to the Secretary such ballot enclosed in two envelopes, the inner one to be blank and the outer one endorsed by the voter.

ART. 12. The rejection of any candidate for admission as member, associate, or junior, by *seven* voters, shall defeat the election of said candidate. The rejection of any candidate for admission as honorary member by *three* voters shall defeat the election of said candidate.

ART. 13. The said blank envelopes shall be opened by the Council at any meeting thereof, and the names of the candidates elected shall be announced in the first ensuing meeting of the Society, and also in the first ensuing list of members. The names of candidates not elected shall neither be announced nor recorded in the proceedings

ART. 14.—Candidates for admission as honorary members shall

not be required to present their claims; those making the nominations shall state the grounds therefor, and shall certify that the nominee will accept if elected. The method of election in other respects shall be the same as in case of other candidates.

ART. 15. All persons elected to the Society, excepting honorary members, must subscribe to the rules and pay to the Treasurer the initiation fee before they can receive certificates of membership. If this is not done within six months of notification of election, the election shall be void.

ART. 16. The proposers of any rejected candidate may, within three months after such rejection, lay before the Council written evidence that an error was then made, and if a reconsideration is granted, another ballot shall be ordered, at which thirteen negative votes shall be required to defeat the candidate.

ART. 17. Persons desiring to change the class of their membership shall be proposed in the same form as described for a new applicant.

FEES AND DUES.

ART. 18. The initiation fees of members and associates shall be \$25, and their annual dues shall be \$15, payable in advance. The initiation fee of juniors shall be \$15, and their annual dues \$10, payable in advance. A junior, being promoted to full membership, shall pay an additional initiation fee of \$10. Any member or associate may become, by the payment of \$200 at any one time, a life member or associate, and shall not be liable thereafter to annual dues.

ART. 19. Any member, associate or junior, in arrears may, at the discretion of the Council, be deprived of the receipt of publications, or stricken from the list of members, when in arrears for one year. Such person may be restored to membership by the Council on payment of all arrears, or by re-election after an interval of three years.

OFFICERS.

ART. 20. The affairs of the Society shall be managed by a Council, consisting of a President, six Vice-Presidents, nine Managers and a Treasurer, who shall also be the Trustees of the Society.

All past (Ex) Presidents of the Society, while they retain their membership therein, shall be known as Honorary Councillors, and shall be entitled to receive notices of all meetings of the Council

and may take part in any of its deliberations; they shall be entitled to vote upon all questions except such as affect the legal rights or obligations of the Society or its members.

ART. 21. The members of the Council shall be elected from among the members and associates of the Society at the annual meetings, and shall hold office as follows:

The President and the Treasurer for one year; and no person shall be eligible for immediate re-election as President who shall have held that office for two consecutive years; the Vice-Presidents for two years and the Managers for three years; and no Vice-President or Manager shall be eligible for immediate re-election to the same office at the expiration of the term for which he was elected.

ART. 22. A Secretary, who shall be a member of the Society, shall be appointed for one year by a majority of the members of the Council at its first meeting after the annual election, or as soon thereafter as the votes of a majority of the members of the Council can be secured for a candidate. The Secretary may be removed by a vote of twelve members of the Council, at any time after one month's notice has been given him by a majority of its members to show cause why he should not be removed, and he has been heard to that effect. The Secretary may take part in any of the deliberations of the Council, but shall not have a vote therein. His salary shall be fixed for the time he is appointed by a majority vote of the Council.

ART. 23. At each annual meeting, a President, three Vice-Presidents, three Managers and a Treasurer shall be elected, and the term of office of each shall continue until the end of the meeting at which their successors are elected.

ART. 24. The duties of all officers shall be such as usually pertain to their offices or may be delegated to them by the Council or by the Society. The Council may, in its discretion, require bonds to be given by the Treasurer.

ART. 25. The Council may, by vote of a majority of all its members, declare the place of any officer vacant, on his failure for one year, from inability or otherwise, to attend the Council meetings, or to perform the duties of his office. All such vacancies and those occurring by death or resignation shall be filled by the appointment of the Council, and any person so appointed shall hold office for the remainder of the term for which his predecessor was elected or appointed; *provided* that the said appointment shall not render him ineligible at the next annual meeting.

ART. 26. Five members of the Council shall constitute a quorum; but the Council may appoint an Executive Committee, or business may be transacted at a regularly called meeting of the Council, at which less than a quorum is present, subject to the approval of a majority of the Council, subsequently given in writing to the Secretary and recorded by him with the minutes. Absent members of the Council may vote by proxy upon subjects stated in the call for a meeting, said proxy to be deposited with the Secretary.

ART. 27. The President on assuming office shall appoint a Finance Committee and a Publication Committee and a Library Committee of five members each. The appointment of two members of each Committee shall expire at the end of each year. The Secretary shall, *ex officio*, be a member of all three Committees.

ART. 28.—The Finance Committee shall have power to order all ordinary or current expenditures, and shall audit all bills therefor. No bill shall be paid except upon their audit. When special appropriations are ordered by the Society, they shall not take effect until they have been referred to the Council and Finance Committee in conference.

ART. 29. It shall be the duty of the Publication Committee to receive all papers contributed, to decide which shall be published in the *Transactions*, and which shall be read in full at the meetings.

ART. 30. It shall be the duty of the Library Committee to take charge of the collection of all material for the Library of the Society, and to supervise all regulations for its use.

ELECTION OF OFFICERS.

ART. 31. At the regular meeting preceding the annual meeting a nominating committee of five members, not officers of the Society, shall be appointed, and this committee shall, at least thirty days before the annual meeting, send to the Secretary the names of nominees for the offices falling vacant under the rules. In addition to such regularly appointed committee, any other five members or associates, not in arrears, may constitute an independent nominating committee, and may present to the Secretary, at least thirty days before the annual meeting, all the names of such candidates as they may select. All the names of such independent nominees shall be placed upon the ballot list with nothing to distinguish them from the nominees of the regular committee, and the Secretary shall at once mail the said list of names to each member and associate in the form of a letter ballot, it being un-

derstood that tne assent of the nominees shall have been secured in all cases.

ART. 32. In the election of Vice-Presidents, each member and associate may cast as many votes as there are Vice-Presidents to be elected. He may give all these votes to one candidate, or distribute them among more, as he chooses. Managers shall be voted for in the same way.

ART. 33. Any member or associate entitled to vote may vote by retaining or changing the names on said list, leaving names not exceeding in number the officers to be elected, and returning the list to the Secretary—such ballot inclosed in two envelopes, the inner one to be blank and the outer one to be indorsed by the voter. No member or associate in arrears since the last annual meeting shall be allowed to vote until said arrears shall have been paid.

ART. 34. The said blank envelopes shall be opened by tellers at the annual meeting, and the person who shall have received the greatest number of votes for the several offices shall be declared elected.

MEETINGS.

ART. 35. The annual meeting of the Society shall be held on the first Thursday in November of each year, in the City of New York, unless otherwise ordered, at which a report of proceedings and an abstract of the accounts shall be furnished by the Council. The Council may change the place of the annual meeting, and shall, in that case, give timely notice to members and associates.

ART. 36. Other regular meetings of the Society shall be held in each year at such time and place as the Council may appoint. At least thirty days' notice of all meetings shall be mailed by the Secretary to members, honorary members, associates and juniors.

ART. 37. Special meetings may be called whenever the council may see fit; and the Secretary shall call a special meeting at the written request of twenty or more members. The notices for special meetings shall state the business to be transacted, and no other shall be entertained.

ART. 38. Any member, honorary member or associate may introduce a stranger to any meeting; but the latter shall not take part in the proceedings without the consent of the meeting.

ART. 39. Every question which shall come before the Society shall be decided, unless otherwise provided by these rules, by the votes of a majority of the members and associates present, provided there is a quorum.

ART. 40. At any regular meeting of the Society thirteen or more members and associates shall constitute a quorum.

ART. 41. Unless otherwise ordered, papers shall be read in the order in which their text is received by the Secretary. Before any paper appears in the *Transactions* of the Society a copy of the paper shall be sent to the author, and, so far as possible, a copy of the reported discussion shall be sent to every member who took part in the same, with requests that attention shall be called to any errors therein.

ART. 42. The Society shall claim no exclusive copyright in papers read at its meetings, nor in reports of discussions, except in the matter of official publication with the Society's imprint, as its *Transactions*. The Secretary shall have sole possession of papers between the time of their acceptance by the Publication Committee and their reading, together with the drawings illustrating the same; and at the time of such reading, or as soon thereafter as practicable, he shall cause to be printed, with the authors' consent, copies of such papers, "subject to revision," with such illustrations as are needed for the *Transactions*, for distribution to the members and for the use of technical newspapers, American and foreign, which may desire to reprint them in whole or in part. The policy of the Society in this matter shall be to give papers read before it the widest circulation possible, with the view of making the work of the Society known, encouraging mechanical progress, and extending the professional reputation of its members.

ART. 43. The author of each paper read before the Society shall be entitled to twelve copies, if printed, for his own use, and all members shall have the right to order any number of reprints of papers at a cost to cover paper and printing; *provided*, that said copies are not intended for sale.

ART. 44. The Society is not, as a body, responsible for the statements of fact or opinion advanced in papers or discussions, at its meetings; and it is understood that papers and discussions should not include matters relating to politics or purely to trade.

AMENDMENTS.

ART. 45. These rules may be amended, at any annual meeting, by a two-thirds vote of the members present; *provided*, that written notice of the proposed amendment shall have been given at a previous meeting.

CONTENTS OF VOLUME III.

[PRESENTED BY TITLE, OR READ BUT NOT PUBLISHED], PAPERS AS FOLLOWS:

* Republished in full, *American Machinist*, June 3, 1882.
† " " abstract, *Mechanics*, April 29, 1882.
‡ " " full, *Mechanics*, May 20, 1882, and *American Machinist*, May 13, 1882.
§ " " " *Jour. Franklin Inst.*
‖ " " " *Van Nostrand's Mag.*, Vol. XXVI., No. 5, p. 401.
¶ " " " *American Machinist*, May 13, 1882.

LIST OF ILLUSTRATIONS, VOLUME III.

PROCEEDINGS

OF THE

PHILADELPHIA MEETING, 1882.

LVII.

PROCEEDINGS

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

FIRST REGULAR MEETING OF 1882,

PHILADELPHIA, PA., APRIL 19TH–21ST.

THE first regular meeting of 1882 of the American Society of Mechanical Engineers was held in the Lecture-room of the Franklin Institute, Philadelphia, Pa., April 19th, 20th, and 21st.

The meeting was called to order at 10 A.M., April 19th.

The following members and guests were present:

Joseph J. Adams,	New York City.
John F. Allen,	New York City.
William S. Auchincloss,	Philadelphia, Pa.
Stephen W. Baldwin,	New York City.
J. Sellers Bancroft,	Philadelphia, Pa.
William M. Barr,	Cleveland, Ohio.
Charles A. Bauer,	Springfield, Ohio.
James C. Bayles,	New York City.
Alfred Betts,	Wilmington, Del.
George M. Bond,	Hartford, Conn.
Elwood Burdsall, Jr.,	Port Chester, N. Y.
A. Hamilton Campbell,	Elizabeth, N. J.
A. C. Christensen,	Brooklyn, N. Y.
Thomas L. Churchill,	Boston, Mass.
John W. Cloud,	Altoona, Pa.
C. C. Collins,	Erie, Pa.
Aug. W. Colwell,	New York City.
George N. Comly,	Wilmington, Del.
J. S. Coon,	Cambridgeport, Mass.
Charles W. Copeland,	New York City.
Alfred B. Couch,	Philadelphia, Pa.
William Cowles,	Newburgh, N. Y.
Eckley B. Coxe,	Drifton, Luzerne Co., Pa.
Gram Curtis,	New York City.
R. H. Davies,	Phœnixville, Pa.

E. F. C. Davis,	Pottsville, Pa.
Charles P. Deane,	Holyoke, Mass.
James E. Denton,	Hoboken, N. J.
W. W. Drummond,	Louisville, Ky.
Thomas Egleston,	New York City.
Albert H. Emery,	New York City.
A. Faber du Faur,	New York City.
John Fritz,	Bethlehem, Pa.
John J. Grant,	Flushing, N. Y.
Robert Grimshaw,	Philadelphia, Pa.
H. S. Hayward,	Jersey City, N. J.
F. F. Hemenway,	New York City.
Gustavus C. Henning,	Baltimore, Md.
William Hewitt,	Trenton, N. J.
J. C. Hoadley,	Lawrence, Mass.
J. F. Holloway,	Cleveland, Ohio.
Robert W. Hunt,	Troy, N. Y.
Frederic R. Hutton,	New York City.
William Johnson,	Lambertville, N. J.
Washington Jones,	Philadelphia, Pa.
William Kent,	Pittsburgh, Pa.
William A. Leavitt,	Philadelphia, Pa.
W. Barnet Le Van,	Philadelphia, Pa.
George B. Mallory,	New York City.
Professor William D. Marks,	Philadelphia, Pa.
Samuel McElroy,	Brooklyn, N. Y.
William Metcalf,	Pittsburgh, Pa.
Alexander Miller,	New York City.
Horace B. Miller,	New York City.
Lycurgus B. Moore,	New York City.
Charles H. Morgan,	Worcester, Mass.
Joseph Morgan, Jr.,	Johnstown, Pa.
A. F. Nagle,	Providence, R. I.
Knight Neftel,	New York City.
C. C. Newton,	Philadelphia, Pa.
William E. Partridge,	New York City.
Franklin Phillips,	Newark, N. J.
George H. Phillips,	Newark, N. J.
Thomas R. Pickering,	Portland, Conn.
David W. Pond,	Worcester, Mass.
Charles T. Porter,	Philadelphia, Pa.
Francis A. Pratt,	Hartford, Conn.
Thomas Whiteside Rae,	New York City.
Charles B. Richards,	Philadelphia, Pa.
Francis H. Richards,	Springfield, Mass.
S. W. Robinson,	Columbus, Ohio.
John B. Root,	New York.
William J. Root,	Brooklyn, N. Y.
W. K. Seaman,	Scranton, Pa.
Horace See,	Philadelphia, Pa.
Coleman Sellers,	Philadelphia, Pa.

William Sellers, ...	Philadelphia, Pa.
Oberlin Smith, ...	Bridgeton, N. J.
Henry F. Snyder, ...	Watsontown, Pa.
Allan Stirling, ...	New York City.
George S. Strong, ...	Philadelphia, Pa.
Ambrose Swasey, ...	Cleveland, Ohio.
John E. Sweet, ...	Syracuse, N. Y.
Robert H. Thurston, ...	Hoboken, N. J.
William P. Trowbridge, . . .	New York City.
W. E. Ward, ...	Port Chester, N. Y.
J. Burkitt Webb, ...	Ithaca, N. Y.
William Oliver Webber, . . .	Lawrence, Mass.
George W. Weeks, ...	Clinton, Mass.
W. H. Weightman, ...	New York City.
Samuel T. Wellman, ...	Cleveland, Ohio.
Joseph J. White, ...	Philadelphia, Pa.
Moses G. Wilder, ...	Philadelphia, Pa.
William H. Wiley, ...	New York City.
Alfred R. Wolff, ...	New York City.
C. J. H. Woodbury, ...	Boston, Mass.

The President: I have to report to the Society in opening, very nearly as I have to do at almost every meeting, that the membership is rapidly increasing. We have to-day on our list two hundred and ninety-four members, and twenty-two have been passed by the Council and are ready for balloting, so that the membership of the Society has become to-day three hundred and sixteen. It is a very remarkable growth for so young an association; and in other respects the Society is as prosperous as could be desired. We have a new catalogue, which includes membership up to the date of the issue of the last year's catalogue, and when the ballots have been counted to-day a circular will be issued by the Secretary including the names of those who have been passed and successfully balloted for, and which can be added by the members to their catalogues, and which will thus make the list complete up to the end of this session. The applicants balloted for to-day will become members, of course, immediately after the business is transacted, and will join us during our meetings and discussions.

One grand event that has occurred since the last meeting has been the incorporation of the Society. The Society is now incorporated under the laws of the State of New York. The date of incorporation is 1881, as you will find on the Society's seal.

The catalogue lately issued embraces, you will find, one or two new features, to which I wish to call the gentlemen's attention. You will find a list of the past officers of the Society, and also the names of our deceased members, Henry Rossiter Worthington and Alexander Lyman Holley. It was thought by the Council advisable to put on record the fact that those members had been not only distinguished members, but also that they were among the founders of the Society, and their names will be kept on this list as honorary members *in perpetuum*. I imagine that no objection will be made, and that those names will always stand, and, of course, our only regret is that such gentlemen cannot be made honorary members whilst living. The provisions of our Rules are such as to prevent the putting on the honorary list of the names of any members in active professional business, so that neither of these gentlemen could be made an honorary member before his decease.

In the programme for to-day we have general business, presentation of papers, and discussions, for this morning, and a memorial session this afternoon in honor of Mr. Holley. That action was taken by the Society partly because of their own views of its fitness, and largely because a similar action had been initiated by the other great engineering societies of the country. Those societies had already appointed committees to take cognizance of the death of Mr. Holley, and as Mr. Holley was one of the active members of the committee forming this Society originally, our indebtedness to him, and our memory of him, should be stronger than in the case of other societies. The action of the committee appointed by the several societies will be presented to us this afternoon, and the Council have appointed this afternoon as the time for holding such a session. Instead of an evening session we attend a reception given to the Society by members residing in the city of Philadelphia, and by other citizens of Philadelphia.

A committee was appointed by the Society, in conjunction with the other societies, the Society of Civil Engineers and the Institute of Mining Engineers, on the advisability of making efforts to secure the restoration of the United States Board appointed some years ago for the testing of iron, steel, and other materials, in the same or some other form, and the

Council considered this of such importance that they set it on the programme as the object of a special meeting, so that you will find on the programme that one afternoon is devoted principally to the discussion of that subject. The afternoon of Friday is given to the consideration of urging the passage of the bill now before Congress for the re-formation of the Board to test the materials of construction. That whole matter will be laid before you by the chairman of the committee, and the way in which it is proposed to operate will be suggested, and the subject will be then open for your discussion. The action of the committee must depend upon the action of the Society.

Should time permit, after that matter is disposed of, we will go on to our regular work of the reading and discussion of papers. We have on our list twenty-two papers. It is hardly worth while reading the titles of them all. Mr. Rae will put on the board a sufficient number of these papers to furnish a day's work, so that we can have some idea of when each one will come up. There are also presented two papers which will be put on the list, if the Society has no objection, by candidates for membership; those of Professor Webb, of Cornell University, and Professor Lanza, of the Massachusetts Institute of Technology. If we can make such progress as to get to them they will be read on Friday. The Secretary particularly desires that members should make it a point to enter their names on the register, with the places at which they are stopping in the city. Then that list will be of service to the members of the local committee who wish to know for whom to get passes. Mr. Le Van informs us that he can get a reduction of prices at hotels for some of the gentlemen here. The Secretary has a collection of guests' badges, and gentlemen who are guests of the Society are requested to call upon him and obtain them, which will identify them as guests of the Society. Gentlemen will also find in the hands of the Secretary a set of cards, which will be found useful as cards of introduction to any point of interest. They will also serve as cards of identification if you are unknown to members of the committee. You will also find a programme of the excursion by water in the hands of the Secretary, and at intervals between sessions he will be ready to distribute all these cards and programmes. Those who wish to go to other

places than those on the committee's list, can obtain escort if they desire. The local committee have made arrangements to provide escorts for those members who are strangers here.

The Secretary also wishes me to state that the bound volume of the Transactions for 1880 is now ready and members can have them The papers for 1881 will be ready for use before the end of the session. The papers of the last meeting are in press, and will probably be in our hands before we adjourn.

There are a number of special committees appointed by the Society, and I would ask those gentlemen who are interested in the matters of which those committees take cognizance to communicate with them, and assist, so far as they can, in the work of those committees. The first is the Committee on Permanent Location of the Society; Professor Trowbridge is chairman, and Messrs. Copeland, Egleston, Merrick, and Hoadley are the other members. The object in appointing that committee was to make provision for the permanent location of the Society. The Society of Civil Engineers has a house in New York, which it now owns. The Institute of Mining Engineers has no headquarters, and it is at a great disadvantage for that reason, and it is the hope of members of those two societies and of this Society, with whom I have talked on the subject, that in the course of time the three may unite in putting up a building, probably in the city of New York, which will be the headquarters of the members in the city. That being done, it will form a centre for the engineering interests of the whole country. That is the scheme which the Committee on Permanent Location has in hand, and Professor Trowbridge will be always glad to receive suggestions, and he and the other members will always be pleased to talk with members of the Society with regard to the best way of accomplishing that result.

There was appointed some months ago, as the members will remember, a joint committee on the invitation of foreign engineers to this country. That scheme was largely the proposal of our friend Holley, and last summer the joint committee—this was a joint committee of the societies of Mining, Civil, and Mechanical Engineers—appointed a sub-committee, consisting of Mr. Holley, of our Society, and Mr. McDonald of the

Society of Civil Engineers, to go abroad and sound the waters on that side, and the idea was that we might possibly get the whole scheme inaugurated, and have the work of this committee completed, so that an excursion could be formed of engineers visiting this country from Europe some time during the coming summer. The gentlemen went abroad, and Mr. Holley's ill health left Mr. McDonald to do the work, practically, and it was found that the times were not ripe for it, and the matter is indefinitely deferred. But the attitude taken by members of the profession over there was not precisely what was desired by our members. There seemed to be a little feeling that there might be some selfish interests involved, and it was concluded to lay the matter aside for awhile, and after a time, when it has been thoroughly talked over in this country and there, I have no doubt that on both sides we shall find the liveliest interest taken in the scheme.

The special Committee on Tests of Iron and Steel we have already spoken of. Of that committee, Professor Egleston is chairman, and Messrs. Leavitt, Metcalf, Oberlin Smith, and Woodbury, are the members, and at the special session to be held, at which that matter will be considered, it will be expected that all members at all interested in the subject will give us their ideas, and enable that committee to form such resolutions, and take such action as will be most effective, and meantime you will find those gentlemen ready to consult with other members in reference to the best way of accomplishing the work.

We also have a self-constituted committee at Pittsburgh. Mr. Lawson has been experimenting there upon steam-boilers, and has obtained some results which are probably valuable and interesting, and several members of our Society living in Pittsburgh, were requested to constitute themselves a committee to attend at these experiments, and report to the Society if they should find anything valuable there. Those gentlemen are William Metcalf, chairman, Reuben Miller, Joseph Reese, F. W. Gordon, James Park, Jr., and James P. Witherow. I hope we may get something of value from them relating to that series of experiments.

The reports of officers are required at annual meetings, but I may say that the Secretary gives us a report that he has informally rendered with regard to the members, etc. The

Treasurer makes a report very similar to that of last fall, stating that he has some two thousand dollars in government bonds, and several hundred dollars of cash on hand, and that he is receiving a very large percentage of dues. There is nothing to indicate that we are going to lose anything in either members or dues.

There are no amendments of our Rules to come up at this meeting. They all pass over to the annual meeting, where only they can be considered.

The first business in order is the reading of the minutes of the last meeting.

On motion of Mr. Washington Jones, the reading of the minutes of the last meeting was dispensed with.

THE PRESIDENT: The next business in order is the counting of ballots by tellers.

On motion of Mr. Jones it was agreed that tellers should be appointed by the chair.

The chair appointed Messrs. Jones, Weightman, Miller, and Henning, tellers.

THE PRESIDENT: If there is no other business, we will proceed at once to the reading of papers. The first step in connection with papers, is the discussion of those which have been deferred to this meeting. There were two or three that were laid over from the last meeting for discussion. It was hoped that members would have time to think about the subjects, and be prepared to discuss them at this meeting, and the Council have directed that it shall be in order for any member to call up any paper that has been heretofore printed, when it is thought that discussion has not been complete, or where new matter can be presented. The order in which we shall read these papers will be dependent largely upon the state of readiness in which we can find them. The first paper is by Mr. Eckart, on the "Chronograph for Engineering Purposes, with the Hipp Escapement." Mr. Eckart is not present, but the Secretary has his paper and will read it.

Mr. Eckart's paper was then read by the Secretary.

PROFESSOR THURSTON then read a paper on the "Several Efficiencies of the Steam-engine."

THE PRESIDENT: The tellers report that the whole number of votes cast was one hundred and seventy-one, and that all the candidates were duly elected. Their names are as follows;

MEMBERS.

Charles H. Loring,	Chief Engineer U. S. N., Navy Yard, Brooklyn, N. Y.
Thomas F. Rowland,	Continental Iron Works, Greenpoint, N. Y.
W. R. Eckart,	P. O. Box 1587, San Francisco, Cal.
John B. Root,	Abendroth & Root Mfg. Co., Greenpoint, N. Y.
William T. Leman,	305 West 55th Street, New York City.
Walter E. Parker,	Lawrence, Mass.
Maunsel White,	Bethlehem, Pa.
William Johnson,	Supt. Lambertville Iron Works, Lambertville, N. J.
David W. Payne,	Corning, N. Y.
H. C. White,	Hartford Engineering Co., Hartford, Conn.
Julius L. Hornig,	Jersey City, N. J.
John M. Hartman,	1237 N. Front Street, Philadelphia, Pa.
T. W. Hugo,	Duluth, Minn.
J. H. Burnett,	80-82 Reade Street, New York City.
J. S. Lane,	Webster, Camp & Lane Machine Co., Akron, Ohio.
Albert W. Stahl,	Engineer Corps, U. S. N., Navy Dept., Washington, D. C.
A. E. Leavitt,	Hartford, Conn.
F. H. Underwood,	Tolland, Conn.

JUNIORS.

Isaac Chase Greene,	P. O. Box 846, New York City.
W. Irving Babcock,	Delaware River Iron Shipbuilding and Engine Works, Chester, Pa.
Andrew J. Caldwell,	Hydraulic Works, Van Brunt & Rapelye Streets, Brooklyn, N. Y.
Lienau Walden,	430 Walnut Street, Philadelphia, Pa.

The session was then adjourned to 2.30 P.M.

Afternoon Session.

The President: The special business of the afternoon, the holding of a Holley Memorial Session, was arranged by the Council on the receipt of communications, as I stated this morning, from the sister societies. Those societies, having appointed committees with reference to this matter, requested that our Society should also appoint a committee to act with them. The Society of Civil Engineers appointed Messrs. Macdonald, Hamilton, Chanute, and Clark. On our part Messrs. Trowbridge, Bayles, Gordon, Coxe, and Hunt, were appointed. The Mining Engineers appointed Messrs. Raymond, Griswold, Prince, and others yet to be named. The records of that joint meeting are on the table, and I will ask the Secretary to read them.

The Secretary then read the records of the joint meeting as follows:

A meeting of representatives of the three committees appointed by the "Civil," "Mining," and "Mechanical" Engineers, to consider what steps should be taken to prepare a memorial to the late Alexander Lyman Holley, was held at the Westminster Hotel, on the evening of March 22d, 1882.

There were present of the "Mining" Engineers, Dr. R. W. Raymond; of the "Mechanicals," Mr. J. C. Bayles, and Professor W. P. Trowbridge; of the "Civils," Messrs. W. G. Hamilton, O. Chanute, T. C. Clarke, Charles Macdonald, and, informally, Mr. J. P. Davis, of the "Board of Direction" of the Civil Engineers.

It was moved and carried "that the committees of the three societies act as a *joint committee*."

Of this joint committee Dr. Raymond was elected chairman, and Mr. Macdonald secretary and treasurer.

It was moved and carried, "That Dr. Raymond be requested to deliver a 'Memorial Address' before an assembly of the three societies, at some future occasion to be decided upon."

A discussion ensued as to the time of holding such an assembly. It was thought that it should not be earlier than the next fall.

It was moved and carried, "That a sub-committee of one from the committee of each society be appointed for the purpose of collecting information, etc., as to the nature and location of a 'Memorial,' and time of proposed joint meeting, and any other necessary details, with instructions to report, with recommendations, to the joint committee."

The members of the sub-committee appointed under the above resolution were Dr. Raymond, "Mining Engineers;" Mr. Bayles, "Mechanical;" and Mr. Macdonald, "Civil."

A general discussion ensued as to the probable cost of a suitable "Memorial," to be erected in Central Park, New York. It was thought that \$10,000 would be ample for the purpose, and it was moved and carried, "That the sub-committee be authorized, if they found on inquiry that a bust or monument could be put up in Central Park for \$10,000, to solicit subscriptions at once without reporting to the joint committee, and that such subscriptions should not be confined to members of the three societies."

A discussion was then had on the publication of a "Memorial Book," containing the Memorial Address, and a comprehensive review of Mr. Holley's life and work.

The members of the separate committees were requested to lay the subject before their societies for further instructions.

Adjourned, to meet at the call of the Chairman.

THE PRESIDENT: That committee have arranged—I think the arrangement is complete—with Dr. Raymond to deliver a Memorial Address before the three societies jointly. I presume that will occur about the time of our annual meeting in the fall. Dr. Raymond requires time for preparation, and I presume it will take time to arrange for a joint meeting. In the meantime, each of the societies has taken some such action as it has been proposed to take this afternoon, and the Council have appointed the afternoon for some special action here. The business of the afternoon is the action of the Society upon this matter as presented by the committee which have delegated one of their number to represent them, and before calling upon that gentleman to speak to us I will read what is, so far as I know, the last communication to this Society from Mr. Holley. At the death of Mr. Worthington, Mr. Holley was appointed to write a few words *in memoriam*, and they were printed, but were never formally presented to the Society. Here the President read Mr. Holley's "IN MEMORIAM" of Mr. Worthington, published in the Transactions of the Second Regular Meeting of 1881, and after some feeling, prefatory words introduced Mr. James C. Bayles, who delivered the Memorial Address.

THE PRESIDENT: The committee present a series of resolutions for the action of the Society, which I will ask the Secretary to read.

The Secretary then read the following resolutions:

WHEREAS, We are called upon as a society to give expression to profound and sincere sorrow in the death of our Vice-President and friend, Alexander L. Holley:

Resolved, That we mourn the death of our friend as an irreparable loss to the profession, and as a sad personal bereavement.

Resolved, That in the death of Alexander L. Holley the country has lost an engineer whose genius and industry have greatly aided our industrial development, and to whom all branches of the engineering profession were profoundly indebted.

Resolved, That we shall ever hold Alexander L. Holley in cherished remem-

brance, as one whose life and example are an inspiration to high views and worthy motives, and who gave a new dignity to all branches of our profession; and that we remember our associations with him as something which made our lives happier and our work lighter.

Resolved, That the Secretary be directed to forward a copy of these resolutions, with the report of our memorial services, to the family of Mr. Holley, with assurances of the deep and tender sympathy we feel for them in their bereavement, and that the committee of five appointed by our Council be directed to coöperate with the committees appointed by other societies in furthering the work of securing a worthy and permanent Holley Memorial, in whatever form may be deemed most appropriate and best calculated to keep his work and example before the rising generation of engineers.

The resolutions were unanimously adopted.

Remarks were made upon the theme of Mr. Bayles's tribute, by Messrs. Fernie, Coxe, Hunt, Metcalf, Charles T. Porter, Hoadley, Holloway, C. Sellers, A. H. Emery, and Partridge.

THE PRESIDENT: We are here as guests of the Franklin Institute of this city. The Franklin Institute is one of the educational establishments of this country which has done most work on small capital. With the possible exception of the Cooper Institute, of New York, this institution has done more good with a little money, than any other in the world A history of its work has been prepared by Mr. Fraley, of this city, and has been brought in by Mr. Sellers, and will be presented among other papers, and put on our records, if there is no objection on the part of the Society. There seems to be none, and it will be placed on the records.

MR. SELLERS: I wish to say that the origin of this paper was a letter from the President of this Society to me, suggesting the great propriety of some member of the Franklin Institute preparing a paper to show the efforts the Franklin Institute had made to advance the mechanic arts. Now, as Mr. Fraley was among the very few members who were members in the year 1854, and who are now members, I asked him if he would prepare such a paper. He has done so with a great deal of care, and it has been placed in my hands, and it is that which I now give to the President to be read by title, and if it is printed, I should like to preface it with a few remarks, which I will not make now, as to Mr. Fraley's real position, and the part he has played in all this. As one who has been intimate with all those great men who made the Franklin Institute celebrated in its day, his narrative will certainly be of interest to all our mechanics.

PROFESSOR HUTTON: It seems to me that it is only appropriate, since this is a Memorial session, that after the regular tributes have been paid, we should at once adjourn. Otherwise, it might appear in our minutes, perhaps, as if we had rather interpolated a memorial meeting into other business. I would therefore move that we at once adjourn.

Agreed to.

THURSDAY, APRIL 20TH.

MORNING SESSION.

The meeting was called to order at 10 A.M.

THE PRESIDENT: There is no business coming before the Society on my list this morning. We can proceed at once to the reading of papers. But I will say before we take up any papers that the Council considered yesterday, the place and time of the next meeting. After discussion, in view of the fact that we had no invitation for next summer, and of the fact that we are proposing to hold a joint convention with the other two societies, to listen to the memorial services conducted by Dr. Raymond, it was finally concluded that when the meeting adjourns, it shall adjourn to meet at the call of the presiding officer, when the time and place of the joint convention shall be determined upon by the joint committee. I presume the place will be the city of New York, and the time probably the early fall. Dr. Raymond wants to be given ample time for the preparation of his address. It will be somewhat lengthy, and I have no doubt exceedingly interesting, and to do the matter full justice, he wishes to take ample time, and do it with perfect deliberation. So I presume the gentlemen may be expected to be called together some time in the early fall, and most likely in the city of New York, in joint convention with the Society of Civil Engineers and the Institute of Mining Engineers.

The first paper on our list is that of Mr. Coon, entitled, "Results of a Test of Upright Boilers and Pumping-Engine."

MR. COON read his paper.

THE PRESIDENT: I see we have present probably as large an audience as we can expect during the session. If it should occur that the meeting of the joint convention of the societies should be set at a late date, there will not be time for the Nominating Committee to do its work. We are compelled by

our By-Laws to appoint a committee to nominate officers for the succeeding year, and in order that that committee may have ample time for deliberation and correspondence, it should be appointed so early that its deliberations will be neither interrupted nor hurried; and for that reason, it will probably be best to provide for the appointment of the committee now. I suggest to the gentlemen that they determine whether to have the Nominating Committee appointed in the interim, or whether we shall wait till the next session. If it should happen that the joint convention should be fixed for some time in September, there would be a very short interval between that and the November meeting; and the members of the committee of last year informed me that they had not, even then, time enough. The time this year will be very much curtailed. I will make a suggestion, with the approval of the Council, that the direction for the Nominating Committee be made now, in order that it may be appointed in ample time to do its work. I wish to remind members that if they have the interest of the Society at heart, as I have no doubt they all have, they will suggest names to the Nominating Committee, sending their suggestions to the Secretary, addressed to the Nominating Committee. Of course it is expected that those nominated should be men prominent in the Society, for what they have done, or for their interest and work in the Society. I presume it will be found that the coming year will be a very critical year in the history of the Society. The adjustment of finances and the regulation of matters of routine will no doubt be well settled in the course of another year; and I presume gentlemen will understand that we cannot be too cautious in providing a good slate. Will you take action on this matter, gentlemen?

MR. WEIGHTMAN: I would make a motion, Mr. Chairman, that the committee be appointed by the presiding officer as usual.

MR. KENT: I think it would be well if it were settled that the Nominating Committee may transact their business by correspondence; so that the views of a member, say from Indianapolis, could be given the same as if he were present, and that, with the suggestion that all the members of the Society be invited to give their views to the Nominating Committee, will greatly facilitate the performance of its duties.

PROFESSOR SWEET: My connection with that matter justifies me in indorsing what the gentleman has said; and to carry that out it would be of the greatest importance that the committee be nominated early.

THE PRESIDENT: I presume it will be necessary to conduct the business of the committee in that way. We certainly cannot appoint a nominating committee of members who are all at one place. It is certainly at the committee's own option, and I presume it must be understood that their work shall be done by correspondence.

The motion was agreed to.

PROFESSOR ROBINSON read his paper entitled "The Thermodynamics of certain Worthington and other Compound Engines." There was no discussion.

THE PRESIDENT: The next paper is one by Mr. Bond, on "A Standard Gauge System."

MR. BOND read his paper.

PROFESSOR ROBINSON: I would move that, in view of its importance to the profession, a Committee be appointed to avail of the opportunity afforded by the Pratt & Whitney Company to investigate its proposed system of standard gauges, and to make such statement to the Society regarding it as shall be found advisable.

MR. KENT: In the experience of the Institute of Mining Engineers, it was found advisable to adopt the rule never to indorse anything. Since they adopted the rule they have in one or two instances departed from it. But the indorsement of the Society as a society is a matter of very little consequence. What is needed is a report by the committee to the Society stating the committee's judgment. The report of that committee is then published to the world, and the world appreciates the report of that committee far more than it would the judgment or vote of any society. I suggest that the committee simply report to the Society, and let the report be published. I have no doubt that the system of Messrs. Pratt and Whitney is worthy of the highest indorsement. I suppose we have reached the limit now of such investigations; that this is the best work of the kind ever done in the world, and that it will never have to be repeated during our lifetime.

MR. LE VAN: We do not suppose that this Society is infallible, and there will be no harm in making this examination.

If we do not take any action in the matter it may die away, and the results of their experiments will be lost.

The motion was agreed to.

THE PRESIDENT: How will you have the committee appointed?

A MEMBER: By the President.

THE PRESIDENT: If there is no objection, it will be appointed by the President, and any suggestions as to who are the proper men to go on the committee will be in order at any time. A memorandum left with the Secretary will answer the purpose. If there are no other remarks in regard to this matter, we will take up the next paper, which is by Professor Trowbridge, entitled "Determination of the Heating Surface of Ventilating Flues."

PROFESSOR HUTTON: I propose to read this paper in abstract. It is a custom which the Society will have to inaugurate before long. The paper is of a distinctly mathematical character.

Professor Hutton then read the paper.

MR. WOLFF read a paper entitled "Economy of the Windmill as a Prime Mover."

THE PRESIDENT: I would say here that Professor Trowbridge presents another paper, which he desires to be read by title only. It is entitled "Rankine's Theory Relative to the Economy of Steam in the Cornish Engine." The next paper on our list, which is also to be read by title only, is by Mr. Curtis, entitled "A Spring Face for Poppet Valves." The next paper to be read is by Mr. Root, on "Screw Propulsion."

MR. ROOT: This paper is not a statement of results obtained. It is merely a proposition for a change in the principle of applying the propelling power of an engine to the water, for the purpose of propelling vessels. My object, in presenting the paper, is to place the matter before practical engineers, and, if it is wrong in principle, and cannot be made to realize the results that I think it is capable of producing, why, of course, the knowledge of the subject, that may be reasonably looked for in this Society, will be sufficient to ventilate any errors that the paper may contain, which is what, I hope, will be done, if any errors are there.

Mr. Root then read his paper. No discussion was elicited.

The session was then adjourned to 2.30 P.M.

Afternoon Session.

The President called the meeting to order at 2.30 P.M., and Professor Egleston, chairman of the Committee on Tests of Iron, Steel, and other Metals, addressed it, after which discussion ensued:

Professor Egleston: I should be very much obliged to all the members if they would send to the Secretary of the Society what they have said and what they intended to say, so that it may be published in pamphlet form as soon as practicable and distributed among the manufacturers for their education and the education of the persons who represent them in Congress. The calls upon me quite recently for such documents as this have been very frequent. I have been told distinctly by certain manufacturers that they would do the work simply for having the credit of having been interested in getting this commission established. It is, therefore, important that the pamphlet should be got ready as soon as possible for distribution among the manufacturers, who are working not only upon their Congressmen but upon their governors and legislatures, and in some cases with very great effect. The passage of the bill at some time is a matter in which every one of us is interested, and I shall therefore be extremely obliged, as chairman of the committee, if the gentlemen will write out as soon as possible what they said as well as what they intended to say and send it to the Secretary.

Mr. Kent: In connection with Professor Egleston's suggestion, I would like to ask if the stenographer is not taking this discussion, and if it will not be written out.

The President: That will come in due course from the Secretary; but it will probably be some time before it will be ready; not as soon as Professor Egleston desires.

Professor Egleston: It is very important that this should be done as quickly as possible. I spoke of certain manufacturers who are coming to me constantly, and writing to me constantly, saying: "If we only had the information, we could bring about the passage of the bill;" and I am sure the discussion which has taken place this afternoon, even if it did not influence any one, would form an engineering document valuable to all of us.

Mr. Le Van: I am satisfied, Mr. President, that if a copy of

these proceedings were made, it would be very important as emanating from this Society.

PROFESSOR HUTTON: I would like, Mr. President, to offer a resolution of indorsement of the plan proposed by this committee, in order that Mr. Le Van's suggestion may be carried out, that we give the weight of the Society, as far as possible, to this question. I would suggest that the expenses that this committee of our Society may be exposed to,—the expenses for the manifolding of the immediate production of these remarks for correction, and of circulating this memorial,—shall be passed through our Finance Committee. My resolution is: "That we indorse the plan proposed by the committee, and that our Finance Committee be requested to audit and indorse the expenses to which that committee is exposed."

Agreed to.

THE PRESIDENT: The next paper is a paper by Messrs. Edison and Porter, entitled a "Description of the Steam Dynamos in the New York Central Station."

MR. PORTER: It is unfortunate that Mr. Edison cannot be here. He is rather slowly recovering from a very severe illness. It is also matter of regret that we cannot show the dynamo fully by way of illustration, but the best that can be done is to let these views from the *London Engineering* of March 10th be circulated. I have a few copies here representing the machines which were sent to London, and are now running there, and representing those which are now being erected in New York, with slight modifications.

My own knowledge respecting electrical problems is of course superficial, but any questions on that subject that may be asked will be kindly replied to by Mr. Clark, the engineer of the Electric Light Company, who is present.

Mr. Porter then read his paper.

THE PRESIDENT: The next paper is to be read by title only. It is by Mr. Samuel Webber, and is entitled, "Comparison of Turbines." Following that is a paper by Mr. McElroy, on "Steam and Air Economy."

Mr. McElroy then read his paper.

THE PRESIDENT: A paper by Lieutenant-Commander Henry H. Gorringe entitled "Steel Ships and Modifications of Models to meet Requirements of the Ocean Carrying Trade," will be

read by title only. The next paper is by Mr. Hoadley, styled, "Experiments on the Specific Heat of Platinum."

Mr. Hoadley then read his paper. There was no discussion.

Adjourned to 8 P.M.

Evening Session.

The President: I would say, before proceeding to business, that the Council had before it the other day the consideration of the method of disposing of our papers. It seems very probable that we may soon have more papers than we can print, and it has been decided to refer all papers to the Publication Committee, they to determine what papers they can print, which are to be printed in full, which in abstract, and which simply by title. The papers, after being read, are to be transferred by the Secretary to the Publication Committee, and they are then to determine what shall be done with them and hand them back to the Secretary, with directions for his procedure, and he then takes charge of the publication.

Before proceeding with the reading of papers we will take up any business that may be offered.

Mr. Oberlin Smith: *Mr. President:* I rise to make a motion, which I sincerely hope I may have occasion to withdraw, in favor of some other, which shall be *better* calculated to attain the object sought. On the occasion of presenting to you a paper on "Experimental Mechanics" last year, at Hartford, I gave notice of a future motion of this kind. Its object is to make efforts toward a future establishment of some sort of an engineering commission which shall represent the best brains and knowledge of all the great technical schools and societies of America, if possible under the auspices of Government, and of a character to be respected and largely followed by our manufacturers, architects, and engineers.

The work of this commission, as proposed, was, therefore: First, experiment; second, collection, systemization, and distribution of information; third, establishing standards. The first section is of almost infinitely greater magnitude than the others, and of far too great expense for this, or a combination of societies, to attempt alone.

As, however, we are now making a movement (which we all earnestly hope may prove successful), toward the reappointment of the Government Board of Tests, which would be all in

this line that we could at present hope for. I shall limit this motion to the two last sections, which are surely within the near grasp of an earnest effort.

You have, probably, noticed that an actual movement is now under way to establish a national standard for gear-teeth. This much-needed work is being done, unaided, by the same Society which gave us our invaluable system of standard screw-threads,—the Institute whose hospitality we are now enjoying, which bears the name of our "past grand" member, the immortal Franklin.

If a local society can accomplish so much, why should we not go further and give this and other matters the prestige of a national movement? A few such other things, needing immediate attention, are standards for lathe-spindle screws, for lathe-centre tapers, for drill shank-tapers, for counter-shaft belt speed, for exact pipe-threads and hose-couplings, for tap-heads and wrenches, for key-seats, for set-screws, for screw-threads below quarter-inch, for machine-screws, for wire-gauges, for bolt-slots and pin-holes in planers, for holes in milling cutters, for dowell-pins, etc., etc.

Therefore, Mr. President, in order to bring this matter into a practical shape for discussion, I move that the Chair appoint a committee to confer with technical schools and with other societies regarding the feasibility of uniting in establishing a national bureau of information and standards, the committee to report at a future meeting.

Mr. Bond: I second the motion.

The President: Would there be any objection to a reference of that to the committee already formed?

Mr. Smith: It would be an excellent idea.

The President: Would you modify your motion that way?

Mr. Smith: Yes, sir; I would be glad to do so. I have not studied the matter much. I wish somebody would say something about it. What was the exact duty of that committee?

The President: Simply to examine the system of standards proposed by Pratt and Whitney, and their method of operation, and to report to the Society, and it is just as well to make that either a temporary or standing committee, and let them take charge of the whole subject of standards. Your resolution can be made to cover that. If you choose to give it that shape it can be done readily.

MR. SMITH: I might add, "and that it be referred to the Committee on Standards and Gauges," already appointed.

THE PRESIDENT: That this duty be referred to that committee?

MR. SMITH: That the Chair appoint a committee or refer the matter to a Committee on Standard Measurements already appointed.

THE PRESIDENT: That would do it.

Motion agreed to.

PROFESSOR HUTTON: *Mr. President:* That brings me to a point which I was proposing to bring before the Society. When Mr. Smith began his motion I thought it was, perhaps, going to cover what I wanted to bring out. It is part of our duty, no doubt, to establish standards and gauges. The motion of Mr. Smith and my motion look towards the establishment of gauges in mechanical things which are measurable. It has occurred in my own practice that there is no one unit which we handle so frequently and about which there is such a degree of uncertainty as what is technically known as the horse-power of boilers. Personally I have been almost what, in the vernacular we should call "badly left," because I considered the horse-power of a boiler to be about equivalent to the evaporation of about thirty-five pounds of water per horse-power per hour. Thirty pounds of water evaporated to the hour is the standard in acceptation in certain parts of the country. Now it has struck me that in slide-valve practice, and in a good deal of our practice, thirty pounds of water per horse-power per hour is not quite margin enough, and would not this Society of Engineers do a great deal if they could establish, either by experiment or by investigation of current practice, what significance we shall attach to that term of the horse-power of boilers? It is a ridiculous expression, but it has got into our terminology, and into our contracts, and it has become fixed. My idea was, therefore, Mr. President, that the Chair should appoint a special committee for the consideration of this subject, say of five, to report at a future meeting upon the subject of the mechanical engineers' standard of what should be the horse-power of a boiler. I would make a motion, therefore, that the Chair appoint a committee of five to report to the Society on that subject

MR. NAGLE: *Mr. President:* Professor Hutton will find this

whole subject of the horse-power of boilers most thoroughly and exhaustively treated in some of the back numbers of the *Franklin Institute Journal*, and it is my opinion that all that can be said upon the subject is already in print, and can be found in the literature appertaining to engineering, and therefore I see no occasion for the appointment of another committee. In view of these facts I should vote against the resolution. I might add that the Supreme Court of Massachusetts has decided that there is no recognized standard for horse-power of boilers, by which the purchaser or seller can be governed, in the absence of an explicit and clearly defined contract; that in the absence of such contract the practice of the boiler-maker must be taken as the meaning of the value of the horse-power of a boiler.

The motion was lost.

PROFESSOR HUTTON: I feel rather inclined to call for a rising vote on that question. I think the decision of the Chair was right with reference to the testimony of the ear. But I wonder if it represents the sentiments of the Society? If I may, I would like to call for a rising vote.

A rising vote being taken the motion was declared to be lost.

MR. OBERLIN SMITH: I move that the Society adopt the following resolution:

Resolved, That the thanks of the American Society of Mechanical Engineers are due and are hereby tendered to the citizens of Philadelphia for the elegant reception which, through their Committee, Messrs. George B. Roberts, A. J. Drexel, George W. Childs, George H. Boker, Dr. William Pepper, and Professor Fairman Rogers, was given them at the Academy of Fine Arts; and, that while they regard the same as a high personal honor, they prize it, also, as a mark of the esteem in which their profession is held in a city owing so much of its well-earned fame to its scientists, its engineers, and its manufacturers.

Agreed to.

MR. WOODBURY: I have a resolution which I wish to offer, and to move its adoption.

Resolved, That this Society tenders its thanks to the Franklin Institute for the use of its Hall; deeming it an honor to hold its sessions in a place of such importance, where engineering first became a recognized and honored profession in this country. Also that the members of this Society desire to express their obligations to the Trustees and Officers of that Institution for the courtesies received at their hands.

Agreed to.

MR. BARR: I beg to offer the following resolution:

Resolved, That to the various industrial establishments of Philadelphia, to whose open doors we have been so cordially invited, we have our thanks to offer, mingled with regrets that want of time prevented us from a general acceptance of the same. To the gentlemen connected with the few establishments to which time permitted us to make a brief visit, including as it does the firm of William Cramp & Son, John Roach & Son, the Baldwin Locomotive Works, William Sellers & Co., the Whitney Car Wheel Works, William Bement & Son, the Southwark Foundry & Machine Company, Ostheimer Bros., and others; and also to Commodore Pierce Crosby, of the U. S. Navy, the Trenton Iron Company of Trenton, the Betts Machine Company of Wiimington, Riehlé Brothers of Philadelphia, and others who gave us special invitations to visit their works, we desire to return sincere thanks for the attentions shown us.

Agreed to.

PROFESSOR HUTTON: I feel a little modest, Mr. President, in rising to this motion.

WHEREAS, the preparations for our enjoyment and for the success of this Philadelphia meeting, have entailed a great deal of labor on the part of our Committees on Regular Meetings, on Rooms and Conversazione, and on the Joint and Social Committees;

AND WHEREAS, it seems only just and kind that the Society should recognize the work which has been so crowned with success, and that the members generally should express their appreciation of it;

Be it Resolved, That the Society tender its sincere thanks to the members of the above committees, for the efficient and gratifying way in which their difficult duties have been discharged in the preparations for this meeting, and during its sessions.

Agreed to.

MR. RAE: I offer this resolution:

Resolved, That the thanks of this Society are eminently due to the Engineers' Society of Philadelphia for its courtesy, hospitality, and great helpfulness on the occasion of our spring meeting, which have contributed in so important a degree to its great success.

Agreed to.

MR. WOLFF: I offer the following resolution:

Resolved, That the Secretary be directed to send copies of the foregoing resolutions to the various persons and firms from whom the Society has received attention.

Agreed to.

THE PRESIDENT: We have offered a paper by Mr. A. Faber du Faur, entitled "Expansion of Steam and Water without Transfer of Heat."

Mr. Wolff then read the paper.

Mr. Oberlin Smith read a paper entitled "The Positions of Views upon Mechanical Drawings."

The President: The next paper is by Professor Webb, on "Belting to connect Shafts which neither Intersect nor are Parallel."

Mr. Webb asked permission to dispense with the reading of the paper in full, and to present the subject orally. He then proceeded:

The point to be discussed is the proper position of two pulleys, upon shafts, which neither intersect nor are parallel, when the former are to be connected by a twist-belt.

The general law governing all cases of belting, when the pulleys are not grooved, is familiar to you all. For convenience let us call the points Z and Z′, where the belt runs off the pulleys, "points of departure," and the line ZZ′ the "departure connective," and let us understand by the "belt-plane" of a pulley, the plane perpendicular to its axis, in which the belt runs; then we may thus state the law, which is evidently true for flat belts: each point of departure must lie in the belt-plane of the other pulley." We will also speak supposing the shafting to be horizontal.

When the shafts are at right angles with each other, the ordinary method of setting the pulleys is correct. They must be so placed, that a plumb-line shall be tangent to both their surfaces, but when the shafts form an acute angle the law is especially inapplicable, and this method of setting is incorrect.

Here a model illustrating the subject was shown, of which the following figure is a perspective view. It consists of a suitable frame, supporting the cylindrical rollers, with their axes horizontal. The lower roller is turned by a crank, and drives the upper one by a belt, which latter, by means of a thumb-screw and a suitable joint in the frame, can be revolved about a vertical axis, and thus placed at any angle with the lower roller.

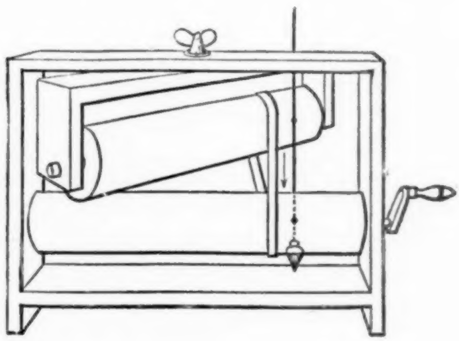
By placing the rollers at an angle of 45°, and a plumb-line tangent at once to both rollers, the incorrectness of the usual method of setting was made evident.

Two ordinary forms of models made in accordance with the old theory were here sketched upon the blackboard. The one

consisted of a drawing on cardboard with a hinge in the middle. Two circles were drawn, one on either leaf, with lines to represent an open belt connecting them. Each circle was tangent to the hinge, and the direction indicated for the belt was such, that the points of tangency were very near the points of departure, and the hinge almost the departure connective. The other, simply two actual pulleys, so mounted that one could be revolved about their common tangent as an exis, while the pulleys were in motion, and without throwing the belt off.

The improved form of model substitutes for the pulleys rollers with no coning, and allows the belt to find its exact place on them.

The speaker then alluded to certain incomplete and incorrect



statements in standard textbooks, and proceeded to show, that the departure connective is not in general a common tangent; also that it is not the intersection of the planes of the pulleys.

These points were illustrated on the model, and the latter was explained as dependent on the friction between the belt and pulley. It was also shown that two belts having different coefficients of friction ran in different positions on the rollers.

Under the latter head it was shown that, before reaching the point of departure, the belt commenced to slip to one side, approaching therefore this point in a curve, which, by developing the surface of the roller, was found to be, when thus developed, a common catenary, whose parameter depended on the radius of the roller, and the coefficient of friction between the belt and the pulley. The speaker then concluded by giving

the descriptive geometrical method of finding the proper position of the pulleys upon these shafts, and with some statements in regard to practical cases.

MR. SEE read a paper, on "Built-up Work in Engine Construction."

A paper entitled "A Note on the Action of a Sample of Mineral Wool, used as a Non-conductor around Steam-pipes," was read by Professor Hutton.

MR. NAGLE read a paper entitled "Feed-Water Heater Performance."

MR. AUCHINCLOSS read a paper describing "A Centre of Gravity Machine."

THE PRESIDENT: We shall be compelled to pass several papers. We have a gentleman with us who has taken the trouble to come a long way with facts that will be of some value to us, and whom, I presume, the members would like to hear. The gentleman is a candidate for membership, and is not a member, and it will require general consent to allow him to present his material. If there is no objection I will call upon him.

The paper which Professor Lanza has been asked to read, as a guest of the Society, contains the results of experiments which would very properly have come into the discussion this afternoon,—"The Strength of Wood Columns as determined at the Watertown Arsenal."

PROFESSOR LANZA: I wish to express my thanks to you, and especially to your honored President, for the privilege I have had of attending this meeting and listening to the interesting papers which have been presented. I also must express my acknowledgment for the privilege of presenting to you the paper which I have prepared in regard to the strength of wood columns.

Professor Lanza then read his paper. No discussion ensued.

THE PRESIDENT: As I said, there are several papers that can only be read by title. One of them is by Professor Robinson, on "The Strength of Members of Wrought Iron and Steel Bridges;" one is by Mr. Johnson, on "The Fly Wheel," and one by Mr. Sperry, entitled "Corrosion of the Propeller Shaft of the Steamship City of New York."

These will be printed in the Transactions, and published in some cases elsewhere. I have here an interesting letter, which

we will not stop to read, relating to the cause of the failure of the Pemberton Mills. If there is no objection the Publication Committee will be allowed to append it to Mr. Woodbury's paper.

New Bedford, Mass., April 13th, 1882.

Mr. C. J. H. Woodbury,
No. 131 Devonshire Street, Boston, Mass.

Dear Sir: I fully concur with your views expressed in regard to mill-vibration.* When mills can be constructed of one or two floors, all the disturbances from oscillation or vibrations can be entirely avoided, and I am satisfied will give superior results during the existence of such mills, as compared with those where these things have not received any attention. When new enterprises are undertaken they are usually entered upon in great haste, and cheapness of construction is the great desideratum, without regard to its ultimate consequences. Durability, the absence of repairs, and the continued running of the machinery, are not given that consideration they should have, and many will have required a rearrangement, and a renewal of machinery, long before the time when it should occur. I was so fully impressed with the importance of guarding against the deleterious effects of oscillation and vibration to the building and machinery that, in the construction of the mill for the Wamsutta Company, of this city, I gave the most thorough attention to the matter, and which I think contributes much towards their success. In January, 1860, at the time the Pemberton Mill fell, I was engaged by your company to go to Lawrence to make a critical examination of the ruins, and spent two days there in doing so. The investigation fully convinced me the fall of the mill was occasioned by the vibration caused by the running of the shafting with imperfectly balanced pulleys on it, and machinery acting on the uneven bearings of the rough castings of the columns on their supports, and the pintles which were between them to form a continuous iron bearing from column to column, from basement to roof. The shaft and ornamentations about the capital were faulty, as they allowed thin places to occur in casting them by a very slight misadjustment of the cores (in some cases there were places in them not over $\frac{1}{16}$ inch thick), and rendered them unfit to support the great weight they had to sustain, while subjected to the hammering process of the vibrations of the floor-timbers, and floors between the supports, during the time the mills were running.

At this time (January, 1860) I was designing and sketching the plans for the Wamsutta Mills, No. 3, and this accident turned my attention more than ever before to the subject of the article you have sent to me, and suggested important changes in my plans.

While at Lawrence examining the ruins of the Pemberton Mills, I made sketches of the columns, pintles, floor-timber, floors, etc., and took the dimensions. I attribute the durability of the machinery in the Wamsutta Mill, No. 1, built in 1847, and Mill No. 2, in 1853, to be due to the extreme care used in the construction of the mill and machinery.

Thomas Bennett, Jr.

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* Mr. Woodbury's paper having been already published, the letter referred to by the President, as above, is inserted here. (Ed.)

PROFESSOR HUTTON: Before the adjournment, I would ask what is the understanding of the Society in reference to the obtaining of discussions of papers by members not present?

THE PRESIDENT: The discussions of those papers are sent with the papers to the members.

PROFESSOR HUTTON: Is it lawful under our rules for an expert member not the author of a paper read, and who was absent during its reading, to introduce observations of his own into the printed discussions, such as he would have made if he were able to be present?

THE PRESIDENT: There has been no precedent in the matter. I should say it would be a matter for the Publication Committee to decide unless objection was offered. It is done in other societies, and I presume there is no objection to it. As it stands now, it is with the Publication Committee. They have everything in their hands in regard to the publication of papers.

On motion the meeting then adjourned.

PAPERS

OF THE

PHILADELPHIA MEETING, 1882.

LVIII.

IN MEMORIAM.

Alexander Lyman Holley, Late Vice-President American Society Mechanical Engineers.

Obiit January 29, 1882.

Introductory.

The President: I feel that I have a peculiar right to speak in this place of the friend and colleague who has left us, to speak of him who was one of the most active among the founders of our Society, and of the man who was the ablest of his generation in our profession. As your presiding officer I stand in the place that he should have occupied, holding the position which he would probably have held had he not himself chosen otherwise, deferring an honor which he hoped, and of right may have anticipated, would be tendered him a little later, when, with improved health, he expected to pass an unbroken year among us.

The brotherly feeling that always unites men who have been taught within the same academic walls came to unite us a quarter of a century ago when we became alumni of "Old Brown." A mutual trust and confidence, such as rarely bind men seeing as little of each other as we did during the succeeding years, came to us, despite infrequent meetings, while the last few years had brought so many opportunities of intercourse that our friendship was cemented with a firmness and closeness of union that is still more rarely experienced among business men. Common tastes and closely related professional pursuits, similar interests, and pleasant memories of much that was common to our earlier manhood, led to a friendship of which the remembrance will never cease to yield sad pleasure to the survivor.

Mr. Holley was one of those who signed the call for the meeting for the formation of the American Society of Mechanical Engineers; he was the principal author of our by-laws and rules, and the leading spirit in the organization of the Society. He was a member of the Nominating Committee, and resigned

in order to oblige his colleagues by accepting a nomination as Vice-President, while positively declining nomination as the first President. He was one of those among the officers of our Society who were always present at the business meetings of the Council, and at all regular meetings, and who never allowed even important private business to interfere with the business of the Society.

No member was more thoughtful in regard to its interests, more prolific of plans for the promotion of its welfare, or more active and earnest in enlisting others in its support, and in bringing the leaders of the profession into our ranks. Mr. Holley was among the foremost in the movement to resuscitate the United States Board to test metals, and to reorganize the great scheme of investigation planned so carefully by that body, but hardly more than planned before the demise of the Board. He was the most active of our members in the organization of the plan for a gathering of European members of the several branches of the profession to meet our own representative men in convention in the United States, and to inspect, under the guidance of our committees, the public works and private enterprises of this country. This thought of a community of work, of pleasures, and of all interests, that should bring into contact all branches of the profession, and all members of our great guild, is illustrative of the breadth of his intellect no less than of his greatness of heart; and these qualities always became prominent in discussing those still weightier matters that had for us a common and more intense interest,—a rational system of education, and a general system of promotion of the useful arts and applied sciences by the united efforts of statesmen, men of science, and men of business,—matters that were always brought into view when, as was so often the case, "The Scientific Method of Advancement of Science" became the theme of our discussion.

Intellectually great, with a noble soul, and possessing the next essential, a powerful and vigorous yet graceful body, Mr. Holley was in all the days of his middle working life one of the finest illustrations of the type of man that Agassiz is said to have been. It was "the soul of a sage in the body of an athlete." But that soul has broken out from even such confinement, and that athletic frame yielded to the strain of the mightier soul temporarily confined within it; and to us is left

only the hope of a future renewal of intercourse and the remembrance of the past.

Our friend Holley was an honest and an earnest man. But such a man is not always the most useful man either to the world, to his fellows, or to himself. The honest, earnest man, who, in the excess of his zeal, deceives himself, is often the most dangerous of characters. The greater his intelligence the more dangerous the man. The greatest crimes that the world has known have been committed by conscientious, zealous men. Such men must possess a better judgment and a greater power of self-control than their comrades if they are to live useful, happy and successful lives.

Holley was an honest, earnest, intellectually great man, possessing that rare and sterling judgment, and having more than a common share of that woman's intuitive appreciation of the right, which is the best regulator of the earnest worker. The faith, the hope, the charity, the brightness, the earnestness, and the wholeness of heart that distinguished him, no less than his great mental powers and his professional standing helped to place him in the high position which he held among men. Shakespeare's admonition in that well-named play, "All's Well that Ends Well," was unneeded by our friend. To "love all, trust a few, do wrong to none," was, with him, second nature. His charity and his love covered all humanity; his faith in those about him, once given, was never withdrawn, except when, by some such bitter experience as we have all occasionally tasted, it was extinguished by betrayal.

Do wrong to none! His whole life was a mission of noblest beneficence, not only to his friends and his acquaintances, to those who loved, and to those who came to him necessitous, but to all nations, to the whole race contemporary with and succeeding him. He was of those few great and fortunate benefactors of mankind to whom we owe the highest material benefits brought to us by civilization.

Our committees are considering how, where and in what form, a suitable monument shall be erected to the memory of this most honored of our colleagues; whether to mount a bust of marble or of bronze in Central Park; to erect a statue at the capital of the United States, or to place some more modest but not less fitting and expressive memorial at his tomb. We may adopt either scheme; if we were to measure his deserts, they

would be beyond all these plans. It is of little consequence which is decided upon; his noblest monument is the memory which is implanted in the hearts of his friends, and in the memories of mankind. If these were not enough, we might erect in the midst of each of those great and wonderful industrial establishments built up so largely by his genius a tablet inscribed with his name, and the legend so familiar to the visitor to Sir Christopher Wren's tomb in St. Paul's, London:

"Si monumentum quæris; circumspice."

Let us hope that the time may come, and that soon, when a still nobler monument than any yet proposed may be built to perpetuate his fame.

The time must come, and that we will hope very soon, when a pressing want of this great country shall be supplied by the establishment of a complete system of thoroughly scientific practical education of the people for their work, a congeries of trade schools and of technical colleges, united into a thoroughly organized and well-administered whole. Such a system it seems now certain must be the work of private hands, and must be built up by the intelligent liberality of comparatively few wealthy and patriotic citizens. We have not yet statesmen in numbers, intelligence, and influence equal to the task of securing a governmental system of education such as has done so much for Germany and France. But the work is begun, and when it has so far progressed that the grand central, crowning, and directing member of the organization, a great UNIVERSITY OF THE ARTS AND SCIENCES, shall have been found and endowed by some noble modern Vaucanson, or Worcester, or citizen more kingly than Ptolemy of Alexandria,—some one, perhaps, of the beneficiaries of the comrade whom we mourn,—let us hope that its most important department may be known as the HOLLEY MEMORIAL SCHOOL OF THE ARTS AND SCIENCES OF ENGINEERING.

If other inscription is needed upon any tablet that may be erected, or upon the pedestal of the monument that shall be raised to the memory of this great man, this worthy successor in fame to the greatest of the inventors of the steam-engine, we may write with fitness and justice a paraphrase of that splendid tribute which may be read on the base of Chantrey's statue of Watt in Westminster Abbey:

Not to perpetuate a Name
which must endure while the peaceful Arts flourish,
but to show
that Mankind have learnt to honor those who best deserve their
Gratitude,
those among the People of the United States and of Europe
who love, honor and cherish his Memory have united
to raise this Monument to
ALEXANDER LYMAN HOLLEY,
who, directing the Force of an original Genius, early exercised
in Philosophic Research,
to the development of the modern Processes of Steel Manufacture,
enlarged the Resources of his Country, increased the Powers of Man, and
rose to an eminent Place
among the most illustrious Followers of Science, and the real
Benefactors of the World.

It is of this man that I am desired, that I myself desire, most earnestly to speak in fitting terms. But I am unable to do so. I have gone to my desk many times during these last sad weeks with the intention of putting on paper words properly expressive of the feelings that are awakened by the thought of our loss. But the words would not fit the thought, and after repeated trials I gave up the attempt. But one evening as I sat at my window, saddened and disheartened, I saw Sirius, that most beautiful and bright of all the stars, rising through the gray mists of the east, his sapphire rays quivering with varying refraction, steadily sweeping upward into the clearer space above, and finally shining out of the invisible dome with the brilliancy of a thousand diamonds, only made the brighter by contrast with the thousands of orbs of lesser magnificence which besprinkled the whole celestial vault.

I watched the progress of that glorious star, from hour to hour, as it so slowly, so steadily, so quietly rose towards the zenith, "ohne hast, ohne rast." After a time a thin cloud barely touched, without concealing, its light, and presently it shone free and clear again, and once more swung magnificently upward. Again, a broader and a thicker veil passed before it, dimming its lustre, and bringing upon me a startling fear lest the beautiful star should disappear forever from view. And even when it reappeared the apprehension remained with me and dimmed the pleasure that its recovered beauty should have given. How soon must a deep and impenetrable shade

conceal it forever. The star still rose, still bright, still beautiful, still wonderful in contrast with the galaxy about it, shining down upon the world with almost, if not quite, all its earlier splendor, blessing the world with light gathered in space away beyond the reach or ken of human minds, and impressing me with a feeling of strength, majesty, invincibleness, such as can only be realized in the presence of the most noble and incomprehensible of all creations.

At last, when nearing the zenith, when in the very height of its glory and beauty, those blue rays quivered again, struggling through the cloudy veil for a little time, flashed through a rift in the black, and disappeared. A shock came to my heart; a sense of desertion, of loneliness, and of grief beyond remedy. Gone forever! But a second thought brought relief. That great and glorious star is still there! It is but a veil of mist, impenetrable to vision, but hardly tangible, that has come between us. Another day will pass and all its magnificence and all its beauty shall again be ours to enjoy.

Another thought brought greater relief: A friend passes from our sight when at the zenith of his fame, in the prime of his manhood, in the height of his usefulness. But why mourn, and why seek to express the selfish sentiments of grief? He still lives. His is still the glory and the splendor of a great soul. Let the tongue be silent! His is the story of the star.

And yet, after all, to many of us who have long known this eminent man, who have found in him a valuable acquaintance, the pleasantest of companions, and the truest and kindest of friends, who, ourselves no orators and feeble even in the everyday use of language, nevertheless feel "more than tongue can tell," or yet "heart can hold in silence;" to many of us it is an unspeakable pleasure to be able to intrust our duty to a representative of ourselves and of the Society, who can, and who will gladly, say what we would say had we the power. For this we gladly turn to one who can give suitable expression to the grief which weighs upon us while we contemplate our loss, and while, nevertheless, we are conscious that our utterances should rather take the form of a song of victory for this immortal, and of congratulation that our friend who has now "passed over," has won so gloriously the peace, and the love, and the happiness of the better life, to which we may hope he may, in due time, welcome all who are left bereaved.

I have the honor to introduce tó the Society the eulogist chosen by our committee to express for us all a common grief, common recollections, and a common hope. I present Mr. James C. Bayles, member of the Society.

LIX.

A TRIBUTE TO ALEXANDER LYMAN HOLLEY.

BY JAMES C. BAYLES, NEW YORK CITY.

Prepared at the request of the Committee on the proposed Holley Memorial.

Mr. President and Gentlemen of the American Society of Mechanical Engineers:

I have been asked on behalf and as a member of the Memorial Committee appointed by our Council, to formally express our deep sense of professional loss and personal bereavement in the death of our honored vice-president and dear friend, Alexander L. Holley. I have accepted this sad duty with satisfaction and with reluctance; with satisfaction, because he was my friend through years of pleasant and, at times, intimate intercourse; with reluctance, because I know that nothing I can say will give fitting expression to the sorrow we feel, each in his own way. Even the language of exuberant eulogy, could I command it, would seem out of place in this our lodge of sorrow, and inappropriate because none valued less than he mere phrases and declamation.

But how can we speak of Holley without eulogy? He was at once so great a man and so dear a friend; we knew him so intimately and loved him so well, that we, at least, cannot speak of him as of others who die crowned with honors gained in spheres of usefulness different from our own. He was one of ourselves, but now that he is gone we recognize as never before his immeasurable worth. I do not mean that he was not appreciated and understood by those of us who knew him best. We ever rated him far above his own modest estimate of himself, and involuntarily paid him the homage of an honor he never courted. But still he was *our* Holley, and now that he has vanished we stand like Gideon beside the wine-press,

when, gazing at vacancy, he knew to whom he had offered the meat and broth of his commonplace daily life. We realize now as never before that in his high sphere of special usefulness, Holley was one of the greatest engineers of his time, and that a generation hence the student of science who scans the metallurgical and engineering literature of this century, will see better than we do now the impress of his name on the corner-stones of more than one of the great industries of the future.

I speak to many who in Holley's death have suffered personal bereavement. To each of us the sad news came fraught with the dread significance of irreparable loss. To each it meant the severance of ties far stronger than we had realized until a pang in the heart revealed the truth. To each it meant a sorrow keen or dull according to the intimacy with which we had known him. Each of us has some legacy of personal reminiscence which, though better worth remembering than telling, is none the less a precious possession—precious if only the echo of his gentle, kindly voice, or the recollection of his earnest face beaming with a light which illuminated all about him. I count it as one of the most striking evidences of Holley's greatness and goodness that we remember him with an unconscious exaggeration of personal admiration. Who has yet heard even calm and impartial comment on his work and worth? When or where is he yet mentioned save with tremulous voice? Who recalls aught but good of Holley, or names him without such tribute of praise as few men merit while living or receive when dead?

In what is meant to be merely a tribute to Holley's memory, it will not be expected that I shall attempt to name or value the results of his varied, conscientious, and skilful professional work. With such knowledge of the subject as I possess, I can at most sketch freely and in outline the incidents of his phenomenal career. Had we time to look more closely we should see that the genius we so greatly wonder at meant simply tireless industry; that he moved upward step by step, by natural and regular development; that the results he accomplished were worked out by close study and clear reasoning. Luck and chance were not factors in the equation of his success. What he did he first knew; what he knew he first learned. There was no happy accident to mark the turning-point in his professional career. His inventions and improve-

ments were but the means by which he sought the attainment of ends kept steadily in view. Thoroughness characterized his habits of thought and of work, and those who knew him best, best knew how carefully he prepared himself for whatever he had to do. In this, probably more than in anything else, we find the secret of his uniform success in all the undertakings and duties of his brilliant career.

It detracts nothing from our estimate of his attainments to know that Alexander L. Holley began life under auspices peculiarly favorable. The child of exceptional parents, and born into a happy and virtuous New England home, the influences surrounding his early life were probably all which could be desired. He was a scion of the true American aristocracy,—an aristocracy of intellectual and moral worth. Knowing neither poverty nor riches, he felt the inspiration of necessary self-dependence without the discouragements and limitations of want. Quick to learn, he completed his studies at school in 1853, choosing the scientific course at Brown University in preference to the classical course at Yale, for which he had been prepared. He was then twenty-one years of age. At once we find him seeking the knowledge which can only be gained in practical work, and without which technical training has so limited a value. He went direct from the school into the large locomotive works at Providence, and for about a year ran a locomotive on the Stonington road. Years after, as President of the American Institute of Mining Engineers, we catch a suggestion of his fruitful experience in this modest capacity, in the striking passage in his address on "The Inadequate Union of Engineering Science and Art," in which he thus describes the relation of the driver to his engine: "The thoughtful locomotive driver is clothed upon, not with the mere machinery of a larger organism, but with all the attributes except volition of a power superior to his own. Every faculty is stimulated, and every sense exalted. An unusual sound amid the roaring exhaust and the clattering wheels, tells him instantly the place and degree of danger as would a pain in his own flesh. The consciousness of a certain jarring on the foot-plate, a chattering of a steam-valve, a halt in the exhaust, a peculiar smell of burning, a sudden pounding of the piston, an ominous wheeze of the blast, a hissing of a water-gauge, warning him respectively of a broken

spring-hanger, a cutting valve, a slipped eccentric, a hot journal, the priming of the boiler, high water, low water, or failing steam; these sensations, as it were, of his outer body, become so intermingled with the sensations of his inner body, that this wheeled and fire-feeding man feels rather than perceives the varying stresses upon his mighty organism."

Thus, unconsciously perhaps, Holley tells us how he carried his responsibilities in all the details of his professional work. It was not perfunctory service for wages or for profit, but a living experience, subjecting mind and body to constant tension. He had put something of himself into every member of the Bessemer plant. The throb of its machinery kept time to his own heart-beats, and he felt, as well as perceived, all the stresses upon the mighty organism with which his life was so closely identified.

At the outset of his professional career Holley began to write for publication. With an unselfish love of truth, he could not conceal or save for his own benefit the fruits of his study and experience. At twenty-three we find him a regular contributor to the technical press, especially to Colburn's *Railway Advocate*. About this time, I am told, there came a marked change in Holley's literary style. His earlier compositions, though enriched by occasional evidences of unconscious genius, were florid and sophomoric to a degree which cannot fail to excite a smile. At once he changed to the simple, earnest style which gave his literary talent the brilliancy of a cut and polished diamond. For this change Holley was no doubt indebted in a great degree to his friend and coworker, Zerah Colburn, and we can imagine what delight those wonderful young men must have felt in an association so fruitful of mutual benefit. Doubtless Holley owed much to Colburn. Without the aid of such a collaborator he would have made his way to substantial greatness; with it the road was shorter and smoother. But journalism, under whatever guidance or in whatever companionship, is an excellent school, and one in which Holley learned much that better prepared him for his life work. At twenty-four we find him proprietor and editor of the *Railway Advocate*, which, founded too early and without an appreciative constituency, suspended during the crisis of 1857. This release from serious and unprofitable responsibilities gave Holley a chance to go abroad for study.

At twenty-six we find him publishing with Colburn, as their joint production, a work on European Railways,* which had an immediate and important influence on American railroad construction and operation. At the age of twenty-nine we find him again started in what gave promise of a brilliant journalistic career. He went abroad as correspondent of the New York *Times*, and the scrap-books in which he preserved his writings are, I am told by Dr. Raymond, who now has them for examination, a mine of wealth from which might be compiled a brilliant and memorable volume. Of the value of his work as a contributor to the newspaper press we can have but little knowledge. That it was potent in stimulating invention and improvement we may be sure. Such work is often valued too lightly. It seems to possess but a transient interest, and to be pushed aside, almost before the ink is dry, by the fresh attractions of the next day's current literature; but every valuable article finds somewhere readers to whom it is worth more than a library of books. The writer for the newspaper press may often feel discouraged by the thought that what costs him so much is so soon forgotten, but every article which is worth remembering is remembered. Like the poet's arrows shot into the air and falling he knows not where, the work of the able and conscientious newspaper contributor exercises an influence he little knows. At twenty-eight, while still a journalist, we find Holley the author of a work on railway practice,† which at once became standard. When we remember that the materials for this treatise were collected at a time when he seemed wholly engrossed in newspaper work, we can but wonder at his extraordinary industry. At thirty, we find him

* The Permanent Way and Coal-burning Locomotives of European Railways, with a Comparison of the Working Economy of European and American Lines, and the Principles upon which Improvement must Proceed. By Zerah Colburn and Alexander L. Holley, with 51 engraved plates by J. Bien. New York. Holley & Colburn, 1858, 4to.

† American and European Railway Practice in the Economical Generation of Steam, including the Materials and Construction of Coal-burning Boilers, Combustion, the Variable Blasts, Vaporization, Circulation, Superheating, Supplying and Heating Feed-water, etc., and the Adaptation of Wood and Coke-burning Engines to Coal-burning; and in Permanent Way, including Road-bed, Sleepers, Rails, Joint Fastenings, Street Railways, etc., etc. By Alexander L. Holley, B.P., with 77 plates, engraved by J. Bien. New York, D. Van Nostrand, 1st edition, 1860; London, Sampson Low, Son & Co., 4to. 1st edition, 1867, 2d edition, 1867.

going abroad for Edwin A. Stevens to study ordnance and armor; and at thirty-three he published a work on these subjects* which was alone sufficient to give him a recognized position in the front ranks of engineers. Meanwhile he had secured for American capitalists the Bessemer patents, and built at Troy experimental works. He had thus reached professional eminence at an age when most men are but laying the foundations of a career. In this department of metallurgical engineering his extraordinary talent found full opportunity for its greatest achievements. How much he did to create the Bessemer steel industry in this country and make our average practice superior to the best foreign practice, has been ably and frankly told by Mr. Robert W. Hunt, of Troy, in a paper before the American Institute of Mining Engineers.† When we remember in how short a time this industry has attained its present extent and prosperity, and with what giant strides it has moved forward to a point at which its statistics overshadow those of Great Britain, we cannot fail to find interesting the story of how this was brought about, chiefly by Holley's persistent industry and close study of details. Fully impressed with the possibilities of the Bessemer process as he had witnessed its workings in England, he inspired others with his own enthusiasm, and under his direction the original plant of the Albany and Rensselaer works at Troy was built. Previous experiments with the pneumatic process as patented by William Kelly, had been made at Wyandotte, in which Mr. W. F. Durfee, of our membership, took a prominent part, and he and his associates are certainly entitled to share with Holley the credit of the first great improvement in the process, the substitution of the cupola for the reverberatory furnace for melting the iron to be charged into the converter. Mr. Durfee's failure to make this improvement successful was due to the small size of his cupola, the distance the iron had to be

* A Treatise on Ordnance and Armor, embracing Descriptions, Discussions, and Professional Opinions, concerning the Material, Fabrication, Requirements, Capabilities and Endurance of European and American Guns for Naval, Seacoast and Iron-clad Warfare, and their Rifling, Projectiles and Breech-loading. Also, Results of Experiments against Armor, from Official Records; with an Appendix, referring to Gun-cotton, Hooped Guns, etc., etc. By Alexander L. Holley, B.P., with 493 illustrations. New York, D. Van Nostrand, 1865; London, Trubner & Co., 1865, octavo.

† Transactions, A. I. M. E., vol. v. pp. 210–216.

moved in the ladle, and the fact that, being low in silicon, it would not generate heat enough to produce the proper reactions when blown in the converter. Holley's success with the cupola was due to better and more convenient arrangements. Though not the first to make steel by the pneumatic process in this country, the Troy works were the first to approximate a commercial success. Early in the history of this industry Holley seems to have concluded that the best foreign practice was merely a starting-point for an ingenious American engineer to work from. His talent was eminently practical, and in his judgment nothing was successful which did not give satisfactory commercial results. The task he had undertaken was a great one. Not only was the process to be adapted to the conditions here existing, but the popular prejudice against the product must be overcome by maintaining a standard of quality which should disarm criticism and command the confidence of consumers. Having made successful the melting in a cupola of the iron to be converted, he began to experiment with American irons, with enough success to encourage efforts on the part of furnace managers to provide a grade of pig suited to the process. The Troy plant was increased by the erection of a 5-ton converter, and Holley then assumed charge of the erection of the plant of the Pennsylvania Steel Company at Harrisburg, for which he had previously designed the machinery. In 1868 he returned to the management of the Troy works, which he partially remodelled in the light of experience gained at Harrisburg, and the improved plant made its first blow in 1870. His next important improvement was the substitution of a 30-inch 3-high blooming train with lifting tables, for the cogging hammer, in the reduction of ingots. George Fritz, a great mechanic, between whom and Holley existed an almost fraternal love, subsequently devised an apparatus which displaced Holley's improvement, and carried economy a step farther. Standing admittedly at the head of this branch of the profession, Holley was called upon to build or design one after another of the Bessemer works, or to assist with his advice and experience the engineers immediately in charge.

Mr. Hunt, in the paper before mentioned, thus summarizes the result of Holley's work up to the year 1877:

"The result of his thought gave us the present accepted

type of American Bessemer plant. He did away with the English deep pit, and raised the vessels so as to get working space under them on the ground floor; he substituted top-supported hydraulic cranes for the more expensive counter-weighted English ones, and put three ingot cranes around the pit instead of two, and thereby obtained greater area of power; he changed the location of the vessel as related to the pit and melting-house; he modified the ladle crane, and worked all the cranes and vessels from a single point; he substituted cupolas for reverberatory furnaces; and last, but by no means least, introduced the intermediate or accumulating ladle, which is placed on scales, and thus insures accuracy of operation by rendering possible the weighing of each charge of melted iron before pouring it into the converter. These points cover the radical features of his innovations. After building such a plant he began to meet the difficulties of details in manufacture, among the most serious of which was the short duration of the vessel bottoms, and the time required to cool off the vessels to a point at which it was possible for workmen to enter and make new bottoms. After many experiments the result was the Holley vessel bottom, which either in its form as patented, or in a modification of it as now used in all American works, has rendered possible, as much as any other one thing, the present immense production."

Of what he has done since this was written we can learn only by a search among his papers. In the position of Consulting Engineer of the Bessemer Association, he worked with tireless industry, but with probably less advantage to his reputation and fortune than had he worked in another capacity. His responsibilities were great, and although his work cannot be said to have been profitable to him in proportion to its value to those for whom it was performed, he was too conscientious to consider his own interests to the sacrifice of theirs. It was not until a manifestation of their feeling of absolute ownership stung Holley's proud and sensitive nature, that he sought to sever this connection by resigning his position. But they were in no mood to part with one on whom they had learned to depend so absolutely. He remained to the last trammelled by a professional engagement he could not resign and was loath to sever, but which gave him a vast opportunity for usefulness in the line of his best abilities.

Considered as an inventor, Holley had fewer claims to recognition than many men whose lives have been of very much less benefit to the world. His talent was more fruitful of immediate results than that of the restless discoverer who is always pushing into the wilderness of possibilities as yet untraversed by the beaten paths of human endeavor. Holley cannot, I think, be called an inventor. He made no great discoveries, and, so far as I can learn, every invention claimed by him had for its object the provision of better means of reaching an end previously aimed at or attained.

His first patent was taken out in 1859, when he was twenty-seven years old. It was for an improved railway chair, and describes a device to preserve the continuity of the track by brackets so attached to spliced pieces and tension plates that the weight of the train wheels on the rail should keep the splices tightly in their places without the aid of plates, nuts, keys, or rivets.

In the same year he took out a patent for a cut-off gear for steam engines, describing an apparatus in which a combination of the motion of an eccentric or its equivalent with the motion of a steam piston for moving a valve, effected a variable cut-off of the induction steam without interfering with a free exhaust.

Ten years passed before he again claimed protection as an inventor. In 1869 he patented a combination of crane, converter, and chimney, so placed relatively to each other that the crane could swing entirely around in its orbit over the converter without coming in contact with the chimney. One side of the converter was supported by a beam, in such a way as to permit a car to be run under it from one side ; and it was claimed that by the arrangement of oven, crane, car, and lift for removing the bottom of the converter, special advantages were gained over those pertaining to the arrangement previously employed. A guide and hand screw were provided in connection with the improved arrangement of parts, so that the ladle stopper could be readily adjusted.

Again in 1869, he patented a shield in connection with a Bessemer converter, for the protection of the workmen. A tuyere box is described in combination with the converter bottom, and the latter was so constructed as to admit of its introduction through the former.

In 1872 Holley patented the converter bottom which bears his name. The patent described a construction of notched bricks shaped so as to be set below and around the tuyeres, the spaces between being rammed with ganister; and to more readily dry the mass screw plugs were provided, which passed through the ganister and boxes.

In the same year he took out two patents relating to the casting of ingots. The first of these describes a mould so arranged as to fill from the bottom to any height desired; the second described suitable moulds, in connection with a solid flask containing suitable runners leading from one mould to another, and lined with a refractory metal to prevent a too rapid abstraction of heat from the molten steel.

In 1873 he patented a stopper for ingot moulds, supported at different points by elastic flanges or friction springs, and on the same date an ingot mould provided with an adjustable cast-iron stopper.

Towards the close of 1873 he obtained a patent on improved rolls, in which the middle roll was adjusted by two screws, one right and the other left-handed, passing through the bolster at either end and operated by worm gearing connected with the pulley above. Fore and catch plates were fastened to lugs on the bolster of the middle roll, and carried by these when the roll was adjusted. A stop on the bolster limited the height to which the metal was raised by the table.

Three years later he invented and patented a furnace construction, in the roof of which were spaces for air, water, or spray conduits for cooling the same.

In 1879 he patented a feeding device for rolling mills, in which the feed rollers were mounted on a special frame provided with suitable mechanism imparting a proper motion, and adapting the apparatus for feeding either long or short pieces. Another device consisted in a rocking frame attached to the housing. The feed-roller frame was carried by the rocking frame, and suitable mechanism is described to guide the pieces and impart a rotary motion to the feed rollers.

Two years later, in 1881—scarcely more than thirteen months ago—he patented a steam boiler furnace, in which the essential device consists of alternate ports, with a diaphragm so placed over them as to thoroughly mix the gases entering through the ports. The space below the diaphragm

constitutes the combustion-chamber in which the gases are burned.

One year and seven days ago * his last patent is dated, which describes the removable converter shell, of which I shall speak somewhat more fully later on.

This, I believe, is a brief record of Holley's work as an inventor of new and patentable devices. The list is not a long one, and the casual reader will not find therein much to sustain a claim to great originality or a talent for discovery. But when we remember what some of these improvements have done for one of the great industries of the country, and how they have helped to place us in the front rank as steel producers, we see that the world owes Holley more than it does many who anticipate industrial progress and stake out claims which succeeding generations may perhaps work with profit, but which when located lie outside the busy circle of the world's activities and industries. I regard Holley's mechanical talent as eminently practical and characteristically American. He ever sought "convenient means." To facilitate, to simplify, to save labor, to economize where economy was profitable,—these were the ends he strove for and attained. Bessemer probably has more claim to recognition as a great inventor than Holley; but if we compare the two men we see strikingly exemplified the difference between the inventor and the industrious engineer. Where Bessemer left the process which bears his name, Holley's work began. It was full of possibilities which Mr. Bessemer, distracted by a restless ambition to do something new in marine architecture and other lines of experiment, not always judiciously chosen, seems to have aided but little in realizing. Holley was content to be useful; the typical inventor leaves the question of utility for others to answer, and pushes on. It is as an engineer, rather than as an inventor, that Holley must be considered great; and not alone as an engineer, but as a teacher of the accomplished facts of scientific progress. He had a faculty for imparting to others the fruits of study, observation, and experience, which is given to but few men. Not only was he lucid and clear in his description, but even around the dry details of mechanical proportioning and construction he cast a glow

* April 26th, 1881.

of color, and truth when he presented it became poetic. How much his writings have enriched the engineering literature of the two continents, I do not need to tell you. Holley's life and work merit all the honor we can pay his memory, and his title to substantial greatness is beyond the reach of question or criticism.

There is something very pathetic to me in all of Holley's death-bed utterances, but especially in those which touched upon his work. "I should like," he said in effect, "to live ten or fifteen years longer to aid in realizing the possibilities of the open hearth process. This would have rounded and completed my professional career; but I am satisfied." To long for an opportunity of further usefulness was natural to one whose life had been so full of great achievements, but to speak of rounding and completing such a professional career seems like wishing to gild fine gold. Not so to Holley! Death to him meant simply leaving undone that for which he had made earnest preparation, and which he desired to do because he could do it best. Others will do good work, great work, but not his work.

The unfinished window of Aladdin's tower,
Unfinished must remain.

Holley's connection with the Society of Mechanical Engineers is a memory of which we may well be proud. Perhaps to him more than to any other member its success is due. His active interest in the project was in itself an assurance that it would realize the objects of its organization, and his name created confidence in all departments of the profession. Some of us, but probably not many, know what effort he made to secure a good attendance at the Hartford meeting, and how anxious he was that the dinner should be a complete and memorable success. He knew better than most of us the value of recreation as a preparation for the serious work of life, and long experience had taught him that to make the social features of our society meetings delightful was the surest way to make such meetings successful. In our dinners we have a perpetual memorial of Holley. On such occasions he enjoyed life at its best, and how much his presence added to our pleasure I do not need to say. Unfortunately, failing health deprived him of the opportunity of contributing liberally to our Transactions,

but had he been spared he would have aided materially in giving us a high place among the great technical societies of the world. I have lately re-read with pleasure and profit his address as chairman of the preliminary meeting in February, 1880, on "The Field of Mechanical Engineering," which is charming in its simple earnestness and brimming with valuable suggestions to officers and members.

We have also on our records the fullest, and, I believe, the first description of his last great improvement,* which is in a striking degree characteristic. Convinced from examination that the basic process was a chemical success, he also saw that it presented difficulties which threatened to make it useless in this country. Having brought the Bessemer practice up to the high perfection which it had attained in the working of the so-called acid process, he recognized the impracticability of restricting a steel plant in the United States to the comparatively small production which satisfied English engineers and capitalists. When Thomas was in this country he and Holley were at Troy together. Thomas was greatly interested in all he saw, and while in the converter-house he remarked that he "should like nothing better than to sit down on an ingot mould and watch the work all day." "If you want to find an ingot mould cool enough to sit on," replied Holley, "you will have to send to England for it." Holley's improvements had rendered impossible the delays which would have resulted from the frequent relining of converters, and to perfect the basic process he had hit upon the clever expedient of making the linings detachable, so that with very little delay a new lining could be substituted for one burned out, and the work go on, enabling our steel-makers to adopt the basic process, when it is to their interest to do so, without sacrifice of product. This was the crowning work of Holley's life, and to us he gave the paper which would have been welcomed by the greatest technical societies of the world.

It is much to be regretted that petty jealousies led to the decision to withhold from Holley the Bessemer medal, which he, more than any engineer, had earned; but he was too great a man to be made unhappy by the fact that he had excited in weaker minds feelings which found no place in his own great,

* "An Adaptation of Bessemer Plant to the Basic Process." Read at the Annual Meeting Soc. Mech. Eng., February, 1880.

loving heart. The consciousness that he merited the honor was worth more to him than to have had it grudgingly bestowed by those who knew, but dare not confess, that he towered high above those who sat in judgment on his claims to recognition. The love of his friends was always worth more to Holley than barren compliment, and he died without uttering a word to indicate that he had known a disappointment in life. Even in the detention of his stricken family, who were hurrying to his bedside, he saw a blessing for them which outweighed the satisfaction it would have given him to look once more upon those nearest and dearest to him; and among his last words was a message that he died without disappointment, knowing that it would be less a shock to them to find their worst fears realized, than it would be to find him unconscious and see him die without even a look of recognition or a word expressing the infinite tenderness of his love. One capable of such forgetfulness of self in the presence of the awful reality of death could look with equanimity on the petty annoyances which make weaker natures unhappy.

Of Holley's personal character, I can speak only as a friend and best describe him as he seemed to me. Perhaps I owe him more than I would care to tell. He won my confidence and regard years ago, when with nothing but youth and inexperience to commend me to his consideration, I sought his counsel and was freely admitted to his confidence. You can estimate better than I can describe the value of such a friend to one weighted with grave and anxious responsibilities, and impressed with a sense of the inadequacy of his preparation for the work devolving upon him. It is the experience of the journalist that truth is sometimes difficult of access. The statements made to him are often colored by a regard for real or supposed self-interest, and misrepresentation masquerades in the garb of frankness and confidence. But when I met Holley and sat with him for half an hour in confidence, I would have pinned my faith to his deliberate statement, otherwise unsupported, against the oaths of all the world. Holley was to me a revelation. Not only was he a man of whose sincerity no one could entertain a doubt, but he was one who dared to put confidence in the sincerity and honesty of others. It was as refreshing to talk with him as to pass from the gray shadows of a closed chamber into the full glow of sunshine,

from the chill of reserve and suspicion into the genial warmth of outspoken frankness. Others I have found honest and true, others have won my love by unselfish service, others have given me wise counsel and judicious advice. Their sincerity I have proved; Holley's sincerity needed no proof.

During the twelve years of an acquaintance which I shall always remember with pleasure, it was my privilege to learn by observation and experience the generous side of Holley's nature. Never have I known him too busy to see one who needed his assistance; never did he promise aid without rendering it. In our great metallurgical establishments are scores of young men who have reason to bless the memory of this unselfish friend, whose timely assistance opened the way to honorable professional success. With Holley there was nothing perfunctory in this service for others. It was his pleasure in a peculiar degree to confer benefit, and he was never so happy as when it was in his power to bring happiness to others.

Of the irresistible charm of Holley's conversation, of his sunny temperament, his brilliant wit, and his genial good-fellowship, I need not speak; but remembering all these I am moved to write on the tablets of memory as his epitaph, a paraphrase of the remark of the old farmer of Marshfield as he stood beside the bier of Webster: "This is a lonesome world and Holley dead."

Responses.

The President: I see among us a gentleman, who, although not a member of our Society, is a member of two of the great societies of Great Britain. I would like, if he is willing, to have him say a few words on this occasion—Mr. Fernie.

Mr. Fernie: *Mr. Chairman and Gentlemen:* Although not an intimate friend of Mr. Holley, yet I had the pleasure of meeting him in this city in 1876; and I know a good deal of his work, and I can bear high testimony, as an English engineer, to the very high appreciation we have in our country for his mechanical skill and genius. He commended himself to us in a great many ways, principally as a writer, as an inventor, and as a connecting link between English and American engineers. So, whenever Mr. Holley came to any of our meetings we looked upon him as your representative, and treated him ac-

cordingly. I assure you that there is a great blank in our societies in England caused by the death of Mr. Holley, and that we mourn his loss as much as you do, for we considered that he belonged to us as he belonged to you. There are a great many small minds in our country, as I dare say there are in yours, who do not look at men with the broad feelings and respect with which they ought, and who regard them in an envious sort of way; but the general feeling of the engineers of our country as regards Mr. Holley was a feeling of genuine respect.

After the eloquent words which have fallen from the last speaker, the most eloquent memorial tribute which I have ever heard, it will be improper for me to express more than my deep regret for the death of Mr. Holley, and to say that we mourn his loss as deeply as you do.

One word in regard to a subject that came before your Society this morning. In respect to a meeting of Mechanical Engineers of England and America, I may say that two years ago I tried to get up a party to come to the United States. At our annual meeting, Mr. Barlow, our President, mentioned in his address the pleasure which a visit to the United States had given him. He was present here at your great Exposition. And after he made that statement I thought it my duty, as having several times visited on this side, to try and get up a party to come across here and see your great works, and try to meet our professional brethren in America and have more fellow-feeling with them. But I found that a long time would be required for such a visit, and that considerable expense would attend it; and although I got Cook, the great excursionist, to arrange about a steamer for us, yet when we learned the length of time it would take, it was found impracticable to get up a party. I believe that is the great trouble with engineers coming to America. I wish we could shorten the road. I hope in a few years we will get it down to six or seven days, and at that time we hope to get a considerable number of English engineers over in America. We have a great many American engineers coming to England, but very few going from England to America. I wish there were more.

The President: The road between England and America is being shortened very rapidly. The Alaska made her last passage in six days and twenty-three hours.

We have among us one of our old officers, who was also

President of the Institute of Mining Engineers. Can we hear from Mr. Coxe?

Mr. Coxe: I have been at many meetings of the Civil, Mining, and Mechanical Engineers at which our dear old friend Holley was present. This, gentlemen, is the first one I have attended since he has gone. As I look around and see so many who have been with us when Holley was here, I feel as if I could say nothing. Holley was a man who made us better. He made us stronger. He made us act like men and feel like men; and I do not believe that there is a man worthy of the name, who has had the honor and the privilege of being well acquainted with Alexander Lyman Holley, who has not found himself a better man. Of him we may well say: "It is better to have loved and lost, than never to have loved at all." I am not speaking of his great genius as an engineer; that is not necessary; he wrote his name as an engineer where none can efface it; but as a friend, as a man, as one who made engineering a profession. And I think to Alexander Lyman Holley the profession of engineering owes more to-day than to any other man who has lived on this side of the Atlantic. Those who were with him in the American Society of Civil Engineers know what he did for its advancement, and I who labored with him for so many years in the American Institute of Mining Engineers know what he did for that Society; and we all feel and must say if we speak the truth, that but for him it is very doubtful if this Society would have come into existence, at least for some time. I feel that I should be but repeating what is in all your hearts, were I to say anything in his praise; and I can only repeat that this is the saddest meeting that I have ever attended. I feel that I would like to go away, as I see his loved face before me there, and think that we are never again to meet upon this earth. I wish almost that I were not here. Gentlemen, let us all try to leave behind us a name like this,—*sans peur et sans reproche*,—the Chevalier Bayard of our profession. He did everything to advance and glorify engineering, and never anything to sully its fair fame.

The President: We have among us another gentleman, who has watched Mr. Holley's work with more intelligence, more power of comprehension, than most of us could have done, and one better qualified to speak of his works than any man among us. We would like to hear from Mr. Hunt.

MR. HUNT: *Mr. President and Fellow-Members:* I can hardly trust myself to speak of Holley. Yesterday I happened to be in the shops of the Corliss Steam Engine Company, and mentioned to one of the workmen there that I expected to-day to attend the memorial meeting of the Mechanical Engineers on the death of Alexander L. Holley. The man exclaimed: "What! our Holley?" And so it is, whether it is among the working-men or among the cultivated engineers, it is to "our Holley" that we to-day seek to pay our tribute.

Sadness is rendered less painful when the privilege is given us of making expression of our grief: "Out of the fulness of the heart the mouth speaketh." Oh how full our hearts have been, and are, from the loss of our friend and fellow-member.. In my reflections upon dear Holley's death, I have so many times thought of the death of his close friend, and one of our most cherished members, one who felt so much interest and filled such an active part in the organization and success of this Society,—Henry R. Worthington.

Many of you will remember that at our second meeting, the one held for the purpose of final organization, Holley was too ill to be present, and Mr. Worthington in his stead read the report of the Committee on Constitution and By-Laws. In a few weeks Holley, having partially recovered, sailed for Europe, where, later, he experienced the terrible sickness which so nearly ended his life. During this time, while his family and friends were anxiously awaiting each cablegram, several professional associates and myself had occasion to visit Mr. Worthington's office. We found him holding a message in his hands, and overwhelmed by grief. His feelings were so overpowering that speech was almost impossible. At last, in eloquent, heartfelt words, he pointed out to us his sorrow. Holley was dying!

What a beautiful tribute he paid to his character. Worthington himself, most genial of men, most pure, most talented, laid his garlands at the feet of one whom he loved for these same qualities. Would that I could to-day pay my tribute to Holley's memory by repeating Worthington's words.

How past all comprehension is fate! Worthington died; Holley came back to us apparently restored to health, and was himself the mourner at the tomb of his friend. And now both are gone. The world has lost much, and of the world this Society is among the heaviest sufferers.

Holley's character is best illustrated by the peculiar marks of affection and respect which have been paid to it since his death. Who would not live such a life? But few can. Such an intellect, such a simple, loving, all-embracing heart is seldom given. But while mourning his loss, we can all endeavor to prove ourselves worthy to have received his love, to have been of his friends.

Whether or no tablets of stone or monuments of brass are erected to his memory, the Memorial Session, at Washington, of the American Institute of Mining Engineers, this of our own Society held to-day, and the action of the American Society of Civil Engineers yet to come, are greater, better, sweeter tributes, tributes such as none but Holley could have called forth.

Nevertheless let us do more, let the three Societies meet in rearing an enduring physical tribute—one alike appropriate to his genius, his love of art, and the good done by him for his fellow-men. Let it stand as an example of the value of practical science, of practical work, and as a beacon to the young men of our country, of whose welfare, of whose guidance, of whose fortune his great heart was so full.

THE PRESIDENT: I see there is another gentleman with us, who is also a member of this and of the sister Societies, who has worked with Holley on the Boards of direction of those Societies, and has himself been President of the Mining Engineers, and is one of our most active and most valued members. Will Mr. Metcalf address the Society?

MR. METCALF: In 1874, I had the pleasure of first meeting the man we have to-day met here to honor. In 1874, it was my fortune one day, as I incidentally dropped into one of the machine shops of our city, to be directed to the pattern shop, and further into a little, dingy corner to find one of the employers. And there in this little dark corner of the place, I met a man who was introduced to me as Alexander L. Holley, and the bright face, and the sweet smile, and the clear intelligent, flashing blue eyes that were set on me that day, are just as clear in my mind at present as they were at that time, and that was my first meeting with Holley. Afterwards it was through his influence that I was induced to join the American Institute of Mining Engineers. It was partly through his influence that I became a member of the American Society of

Civil Engineers, and it was altogether through his influence that I became a member of this Society. To him I owe the great honor of having the nomination to the office of President of the American Institute of Mining Engineers, and when called upon to-day, Mr. President, to speak of Mr. Holley, I hardly know what to say. Of his career, of his professional work, many gentlemen here to-day know far more than I do; and I have simply jotted down a few remarks to add as a tribute to the character of Mr. Holley, which I hope will be deemed at least worthy to go upon the records of this meeting, which is intended, as I understand, simply to be a tribute to the memory of a man who was all love, honor, and respect.

We all know why we loved Mr. Holley,—simply because we could not help it. Not merely because he was sweet-tempered;—many a man has a sweet temper and is insipid. Not only because of his knowledge, for many a one is learned, and no one else is ever allowed to know it. Not because of his many-sided attainments, for many people acquire many things only to air their own vanity. Holley had sweet temper, profound knowledge, and a great variety of attainments, and he poured them out so lavishly, so persistently, and best of all so modestly, that he drew us all to him whether we would or not. But in what was Holley great? He was great in his far-seeing apprehension of the utility of things. He had the enthusiasm of a zealot, the courage of one convinced, and the energy of inspiration. He seized upon the great Bessemer process when capitalists were afraid, when old practices and ignorant prejudice derided it, and when a slumbering world had no idea of its own needs. He gave courage to capital, bent down ignorance and prejudice, and showed an astonished world what a poor world it was before. He was successful in probably the greatest of engineering feats, for his task was no wide chasm to be spanned, no great mountain to be pierced, no large river to be guided and controlled, nor a huge swamp to be filled up and made useful.

These are all great works, but their accomplishment depends mainly upon common-sense, and the knowledge and application of well-known and changeless laws of nature. Once completed they stand fulfilling their objects and requiring but little care for their preservation.

Holley went to the capitalists and said, "Give me your

money, and I will span the great chasm between now and to-morrow ; I will blow to atoms the mountains of ignorance and prejudice ; you shall float upon rivers of wealth ; and old ways and old methods shall be completely swamped. I will take your dollars and convert them into buildings, and furnaces, and mills, and hammers ; I will put all of these fair structures into the hands of the most ordinary men, and they shall do all they can to smash and tear them in pieces. They shall fail ; I shall succeed, and you shall be rich." He did succeed, and why ? How could this man, poet, artist, architect, lover of all that was beautiful, succeed in such a task ? He did it because he was modest, and kept himself in the background. He pushed everyone but himself to the front, and the front rank bore him aloft on its shoulders, and he fulfilled his promises. The little streams of thousands, invested in his many contrivances, united into a great river of millions, and his patrons still gathered up the profits. And here is the great secret of his success. He never allowed his love of the beautiful to get the better of his sense of the useful : and he never allowed his ambition to overcome his faith to the trust reposed in him.

He was happy when he saw each new work completed and running successfully, but he was most happy when he could say, "They are working economically and making lots of money." All I have said seems as nothing, Mr. President, and I can think of no more fitting words to close than those of a friend whom I met the other day, who said : "I cannot tell you how I miss him."

THE PRESIDENT : We have with us a gentleman who has been in a certain way a co-worker with Mr. Holley, and who has helped him through a good many of his difficulties, and whom in turn he has helped very much. There was a sympathy between those two gentlemen, such as I am sure would justify me in calling for Mr. Charles T. Porter.

MR. PORTER : *Mr. President :* In coming here, I confess to you, sir, it is not the great engineer, it is not the man of strong purpose and heroic endeavor, it is not the foremost figure in the band of giants who have created the great steel industry of this country, neither is it the brilliant writer, nor the man of high and varied attainments, whom my memory most loves to dwell upon ; oh, no ! Alexander Lyman Holley was all this ; but,

sir, he was a great deal more than this. That beaming countenance with speaking eyes, upon which it was such a joy to look, and which, to everyone who ever gazed upon it, it will ever be such a joy to remember, was the outward manifestation of a great soul, instinct with every feeling, that, in the appropriate words of another, can ennoble or can adorn our nature.

The opportunity for studying Mr. Holley's character, which I enjoyed for the past few years, enabled me to form an estimate of it which is more high than I can very well express. It seemed to me, it always has seemed to me, as if Mr. Holley combined in a wonderful degree, strength and elevation of character, with warm, loving sympathies and sensibilities. It seems to me, sir, as if it could be fairly said of our dear friend, that whatsoever things were honest, whatsoever things were just, whatsoever things were pure, whatsoever things were true, whatsoever things were lovely, that to all such things he was ever loyal. These were the things which called forth all the enthusiasm of his nature, and with which his every heart-beat throbbed in harmony. Such a character, Mr. President, as that of Mr. Holley, must leave an unusually marked impress upon the great number of his co-workers, by whom he was admired and loved; and it is a joyful thing to think that, as it ought, so it must, tend thus to perpetuate itself in ever-widening circles, however they may grow more faint, throwing its spell upon everyone who comes however remotely within the sphere of its influence. And so we can write his name among the names of those who not only have added to the material good of their fellow-men, who not only have contributed largely to the advancement of our civilization, but through whom men have been made better, have been made more just, have been made more generous, have been made more pure, have been made more loving.

THE PRESIDENT: I will next call upon Mr. Hoadley, of Lawrence.

MR. HOADLEY: *Mr. President and Gentlemen:* I received information from the committee having the commemoration in charge, that a few minutes would be accorded to me to speak of my regard for Mr. Holley, and I received this invitation with profound satisfaction, and have spent hours in pleasing melancholy, thinking over the associations that have taken place between us. When I consider how few and

how far between were the occasions when we met, and upon how slender a foundation of actual personal intercourse was based the strong and warm personal regard I have always entertained for Mr. Holley, I feel that it must be futile for me to attempt to account to you for the feeling I express, which might seem, therefore, extravagant; and that it would be entirely idle for me to dwell at any length upon his career, which is quite as well known to you all as to me.

Almost twenty-five years ago, when Mr. Holley was a very young man, I intrusted to him a delicate negotiation in England, when he was about to go to England with Mr. Colburn to prepare their joint work upon European railways and machinery. He performed this negotiation with great tact and delicacy, but with characteristic generosity he declined to receive any compensation, and could only be induced by considerable urging to accept a trifling remuneration for personal expenses. A few years later, in 1863, I met him in London. I was almost ready to go home, and Holley had arrived but a few days. He was seeking at that time to make arrangements with Mr. Bessemer for the manufacture of Bessemer steel in this country. With a perspicacity entirely characteristic of the man he had perceived the transcendent importance of this invention, which was almost unnoticed by the world, and before Mr. Bessemer had ever received a shilling of legitimate compensation for his invention. True, it was the year he had received a present from Sir John Brown of two thousand dollars. Mr. Brown told me that so far they had made no money, but he was confident there was money in the future. In that stage of the invention, Mr. Holley perceiving its great importance, with his own true-hearted loyalty, went directly to the man who had invented the process to get at the very limit—the utmost outpost of the invention, and we all know how much farther he has carried it.

Afterwards I occasionally met him, so rarely that of course we only entered upon the most ordinary themes of professional interest. Life, and destiny, and the loftier speculations of human thought were never even approached. His character was so lovely, so transparent, it spoke so plainly in his clear, calm eyes and in all his ways, that no one could doubt, at least I entertain no doubt, that he was a sound and true man in every respect, in heart and in character; as we all know him to

have been in his chosen profession. As to his profession, as to the physical sciences generally, it is sometimes made a reproach to them that they fix the attention too exclusively upon phenomena, and therefore ignore essential verities; that appearances are much too opaque, and that behind the veil of appearances there is something undiscerned by the scientific eye. On the other hand, men of science say they see too clearly to be deluded by dreams and superstitions. And, therefore, these concurrent views of the same aspect of human life point in the same direction. They are like two sides of a tapestry. About all this, in connection with Mr. Holley, I know nothing, nor do I care. What is doubt but an ambiguous term? And denial itself is only negative faith, and the sign you know changes by transposition to the other side.

And though to us who "know in whom we have believed," doubt may seem dismal and denial dreary and dark, yet when we see the hollow, shadowy forms, that pass in the name of faith, doubt—denial itself—seems seraphic devotion, beatific vision, compared to that heartless assent and shallow acquiescence which give a too ready *credo* to the incredible. I do not know why I should have said all this of Mr. Holley, because I have not the slightest doubt that upon all that relates to the higher problems of life his mind was clear and poised, fixed upon firm conviction as upon all matters of physical science. I need not say that I loved him; all loved him. "None knew him but to love him, none named him but to praise." And if I should reiterate much that has been better said, as I should have to do to express my feelings, I should say that I have but little to give as a rational basis for those feelings; and therefore I will claim your attention no longer.

THE PRESIDENT: We have with us a gentleman who has come from the West, for the purpose of presenting a tribute to the memory of our friend. Mr. Holloway, I think, is in the room.

MR. HOLLOWAY: It is now nearly twenty years since first I met Alexander L. Holley. At that time, at the request of some gentlemen who were about to establish works in Cleveland for the manufacture of steel by the Bessemer process, I made a visit to Troy for the purpose of witnessing its manufacture there, and to take note of the appliances by which it was accomplished.

Upon my arrival in that city I sought the location of the

steel works, which, as I remember, was in a somewhat rural district below the city, on the banks of the Hudson. Arriving at the spot I entered a small wooden building, which seemed to be office, drawing-room, and store-room combined; it contained among other things as I well remember a large table, and one side a row of shelves upon the wall. Upon the table and upon the shelves were short bars of steel, sections of rails, lumps of iron ore, specimen pigs of iron, and pieces of boiler-plate. The bars of steel were bent and twisted into various shapes, and the boiler-plate was flanged backward, forward, and doubled upon itself, and the corners drawn down into small rods, which were tied into all kinds of fantastic loops and knots, all tending to illustrate the wonderful tenacity of the material from which they were made. I knew not where the specimens were made, or where the material came from, but supposed them to be from the newly discovered Bessemer steel as made in England. While looking over the contents of the table Mr. Holley, who had been sent for out in the works, came in. I had read with great interest his paper, the "Railway Advocate," and his work on "European Railways," and had been charmed with his contributions to the New York *Times* over the signature of "Tubal Cain," and I confess I was a little disappointed as I looked upon the slender, young-looking fellow who stood beside the table and before me, but the frank open-heartedness of his manner, his bright hopeful face, and his modest bearing, left an impression upon me years have only deepened, and time will never efface. I was taken through the works by Mr. Holley, and shown all that had been accomplished up to that time, and it was little enough. The works were then idle; they had built one plant and had tried to operate it by water power, and had failed; they had then built another, and a larger one, expecting to work it by steam, but owing to insufficiency of boiler-power and for various other reasons, that had not been a success. I remember how fully and frankly he spoke of all these failures, and how hopeful he was of the future; he said that when they procured new boilers, and changed the blowing engines somewhat, and found a material that would stand for lining the vessels, and come across the right kind of pig-iron, he thought it would be all right. Knowing little or nothing of this new process for making steel, and seeing so little evidence of success in the

surroundings, it seemed to me to be an almost hopeless undertaking. There were only two things about the whole place that looked at all encouraging; one was the table, with its twisted and bent bars of steel, the doubled and knotted specimens of boiler-plate that lay upon it; and the other was, the young man who modestly stood beside them. A few days ago, after an interval of all these years, I again stood within the steel works of Troy. To you who are familiar with the Bessemer steel plant of to-day no description of the place is required, but the contrast between it and its surroundings, and the little experimental works I had visited there twenty years before was marvellous. The quiet, rural surroundings were all wanting; the peaceful air which had previously pervaded the spot had given place to a hum of industry which encircled the whole country about. The very air quivered with the pulsations of immense fans and blowers, which swallowed up the atmosphere by tons and poured it into vast furnaces and converters; ponderous hammers shook the ground you stood upon; or as you picked your way about the works, amid the din of clashing wheels and the escaping steam from out a hundred panting engines, fiery little locomotives chased you over tortuous paths, dragging behind them cars laden with glowing ingots, whose passing left a fierce sirocco in the air; but amid the roar of leaping flames, the brilliant coruscations that filled the air with grandeur and beauty, I saw only the table of long ago with its curious specimens, and the young engineer standing beside it. The history of these intervening years is known to most of you to some extent, but to none has its trials, its disappointments, its struggles, and its failures ever been fully divulged. He who suffered them bore them bravely, uncomplainingly, and the study, the hard thinking, the patience and courage which were so necessary, not only for himself but for those with whom he was associated, can never be fully known by anyone. How the metal that was in the man, as well as the metal he sought for and which lay within the reach of the process he introduced, both have triumphed in these later years you all know. One has made all roadways safe and pleasant, and the other has opened up pathways in all our lives which, lighted up by his genial wit and humor, no coming cloud can now obscure, and which only the twilight of our own lives will mellow ere its light goes out forever.

To the Society of Mechanical Engineers in this the early stage of its existence, the death of Alexander L. Holley is a great loss. How earnestly he interested himself in its formation is known to you all; how valuable would have been his advice and counsel, his spoken and written contributions, had his life and health been spared, all can well imagine. It was ever his constant effort to raise the standard of engineering science, and to elevate to the high position he felt that the engineer was entitled to, all who made it a practice or a profession. You who still possess the engineering paper which, in connection with the late Zerah Colburn, he published in his youth, will find within its yellow faded leaves many an editorial in which he strove earnestly to incite the engineers of that day to make themselves worthy of the position to which their high calling entitled them. His helping hand was ever stretched out to lift upwards, his cheering words went through the ranks urging all to come up higher; and the rich legacy he has left us of an honored and world-respected name, is one which the Mechanical Engineers of America should ever prize. He was the Moses who led us out from the old bondage of cant and custom, which made the engineer a worker only and not a thinker as well. College-bred as he was, donning the costume of the locomotive engineer he mounted the foot-board, and cajoled and manœuvred the rickety engine of that early day over the still more rickety roadbed over which it then ran. It was the saying of a celebrated and somewhat eccentric inventor and engineer, as illustrative of the various conditions of a life which fortune and misfortune had brought to him, that he had at times dined in the palaces of the great, where the plate upon the table was worth a duke's ransom, and so downward through every varying stage of descent to the twopenny bench under a bridge, where the battered iron spoons were chained to the table to keep the guests from stealing them. Inversely, our friend and associate from the foot-board of the little Jersey locomotive made honest, manly strides upwards, until he became the honored, welcome guest in the highest circles in foreign lands as well as in our own. It was not because Alexander L. Holley was a graduate of a college or university that I loved him, it was not because he was a practical workman and engineer, it was not because he was a brilliant and graphic writer, nor was it because he was

as well a learned and argumentative one; not because he could stand up before any society, no matter how technical or scientific, and deliver an essay which for its depth of research, originality and comprehensiveness would rank with the best; it was not for the reason that at the social gathering, where wit, humor, and good fellowship held the hour, that he was the plumed knight about whom all loved to gather, and from whose well-filled quiver he launched repartee and response, and where he parried and thrust with his lance-like wit, hitting everywhere, wounding nowhere; neither was it because he was ever the kind, courteous, considerate gentleman; in short, it was not for any one of these things he won the high regard he so richly deserved; but it was because that he of all the men of his time and age, so far as I know, combined all these commendable qualities in one. The truest test of his goodness now is that in this steady upward march his noble manhood disarmed all criticism, allayed all jealousy, making no enemies, winning all hearts.

Let us remember his fame is our own, winning it as he did by hard study and toil; as he rose to the high eminence he occupied he lifted the profession with him, and the standing of all mechanical engineers the wide world over is higher to-day for the labors of his life, and for the works he accomplished; and if there is any one thing more than another left us to do, it is to emulate his example and to keep his memory green.

The President: I will call upon Mr. Coleman Sellers.

Mr. Sellers: I regret exceedingly that I was not able to come earlier to this meeting so as to hear the addresses delivered by Mr. Bayles and those who spoke later. Probably they covered the ground better than what I can say now. For want of particular knowledge as to what they have told you, it would probably be better for me to confine my remarks to some little instances that occurred in the life of Mr. Holley that may be interesting. My acquaintance with our dear friend began many years ago, when he was connected with Mr. Colburn, as the last speaker remarked, in that little paper which has now become yellow with age. I hardly know how to consider the different events of his life. Looking over a memorandum-book a few days ago, for an entirely different purpose, I stumbled upon a period when Mr. Holley's name seemed to be written on almost every page, and that was the year 1861, at

which time he was imbued with the idea that a locomotive traction engine for common roads would be a very desirable thing; and in connection with Mr. Holley I worked for many months on this traction engine. At that time our forts had been fired upon, and everything was confusion and fear, and it seemed that the whole attention of mechanics would have to be given to furnishing the government with materials for war. It was then that Mr. Holley turned his attention to the more important work of making Bessemer steel. But there is a little incident that I should like to present to you. A gentleman some little while ago, writing from New York, asked me for a definition of "set screw." Unfortunately, he said, he could not find a definition which he could use in a suit at law. I told him he was mistaken, and that the definition could be found in Webster's dictionary; and the reason I knew it, was because Mr. Holley had put it there. Mr. Holley called on me once to have one of those little chats that we used to enjoy so much. He said that he came for the purpose of getting my help in preparing the technical terms on mechanical science for Webster's dictionary. So we went through the shop to get those words, and thus it came that the definition of a "set screw" was one of the terms which Mr. Holley and I worked out together.

Now, all those little things are pleasant recollections to me. It seems as if there was no period in my life as an engineer into which Mr. Holley did not enter. He would come and have a long talk about this society, what was absolutely necessary for its vital existence, and urging the preparation of various papers that would be required; and it was only a very short time before his death that we had one of those delightful conversations. But there was a little talk that I had with him on the Hudson River Road that was so characteristic of the man that I think if I relate that alone it will be sufficient for my contribution to this commemoration of Mr. Holley. We had been up to Troy, and we had gone over the Bessemer Works there. We had dined together, and there was a party of ladies and gentlemen in an apartment of one of the cars. They did not know very well all the places along the road, and made inquiries about them, and finally the conversation turned upon the style of architecture that obtains in some of those beautiful buildings that stud the Hudson. Holley said: "Do

you know I would like some day or another to deliver a course of lectures on architecture applied to mechanics." I said: "I hope you will. How will you handle it?" "Don't you know," he said, "that you and I have had a good many talks about the abominable practice of putting different styles of architecture, Gothic and what not, into steam-engines and other machines. We know perfectly well that what is the most fit is the most beautiful." And so he went on talking in the way in which Holley only could talk about the possibilities of the lecture which would be of eminent use to mechanics in showing the law which obtains in regard to everything, that utility and fitness constitute beauty. Just what nature has done in adapting each tree and each part of it to its proper use is applicable to machinery, and each deviation from that is only an abnormal condition. This was soon after the fire in Chicago and he said: "Have you seen Chicago since the fire? Have you seen the wonderful buildings that have been erected there? Chicago has risen like the Phœnix from her ashes, and yet you will find there the most striking instances of the barbarity of the American people, and their low condition in regard to fitness and propriety. In Chicago they have erected numbers of handsome buildings, and some of the noblest specimens of architecture have been put into their stores and warehouses, but what else have they done? All these beautiful pieces of architectural ingenuity are plastered from top to bottom with signs,—cigars, snuffs, tobacco, dry goods,—covering the whole city of Chicago with black and gold, after putting millions of dollars into those buildings in which the highest skill in construction has been displayed. Now," he said, "we must educate the American people up to such a condition that those things will be impossible. It certainly shows the very low condition of the æsthetic element in the country that they are capable of defacing these beauties with this mere advertisement of their goods in such a glaring way." That was so characteristic of Mr. Holley that I would like very much to see it put upon the record. Had he lived, I think, because he frequently referred to it afterwards, he would ultimately have worked up this particular subject. He would have found many more willing ears to listen to him now than at the time he talked to me. The very thing he advocated so earnestly is having its effect.

It is useless for me to say anything to you about his genial qualities. You all know more about them probably than I do. It is very unfortunate that the city of New York is a great way off from the city of Philadelphia, and we did not see each other as often as we would like to,—Philadelphia being a suburb of New York, of course. But there were times when he would come over here. When he was in London ill, and every steamer was watched to bring the news of his condition, there was one very pleasing thing connected with it all, and that was that gentlemen connected with the paper which his former partner had originally founded (I speak of the *London Engineering*), had taken Mr. Holley to their own home; and when I heard of all the care and comforts that were thrown around him by these brethren of ours on the other side of the water, I must say that I felt heartily grateful to them for all that they had done; and if any word I am saying now ever reaches there, I hope it will convey at least my thanks for what the people of England did for Mr. Holley while he was in such deep distress. I think, Mr. President, that I can add nothing more, but I have given this as a little tribute to his memory.

THE PRESIDENT: In the formation of this Society, there was a good deal of work done in preliminary organization, and, as I remarked at the opening, Mr. Holley had a great deal to do in that preliminary work; but back of what is known and seen, there is a history under the surface of things unknown and unseen. You remember that the call for the organization of the Society was issued with Professor Sweet, I think, as the moving spirit in the organization. He was assisted by two or three friends; and among those who have done so much in the preliminary work preparatory to organization is one whose name I find on the list presented by the committee as one of the gentlemen ready to speak, an ex-officer of the Society, the gentleman who took charge of our funds, and who in his connection with the Society became even more than formerly a very intimate friend of our deceased member,—Mr. L. B. Moore.

MR. MOORE: *Mr. President:* In accepting, with diffidence, and, I am not ashamed to say it, in accepting with tears, the opportunity to add a few words to the tributes already paid, if anything can be added that has not been better said, it has

seemed to me that there is no truer way to honor the dead than to point a moral for the living. In the illustrious life, the close of which we meet this day to commemorate, there are two or three characteristics which have especially impressed my mind. One is the genial light-heartedness that not only made Holley so agreeable as a man, but that also helped so largely to make him what he was as an engineer. Nor was he one of those who, by nature doleful and sombre, strive to cultivate a cheerfulness which they do not feel. To me it has always seemed that Holley was one of those men who could never by any stress of circumstances be borne down, or become permanently soured, because he carried within him the ingredients that go to make up mental health and moral sunshine. His mind was not burdened by the habitual croakings and uncertainties and dejections that are so often mistakenly deemed the ripe kernels of thought, when they are only the husks that hide or smother them. Then, too, closely connected with this trait of his character, and reacting upon it, was entire freedom from the petty spites, and personal and professional jealousies, which too often disfigure abilities of even the highest order. Holley's career is additional proof that it is mainly the light-hearted and buoyant-minded men who rule the world. Another reminder that runs logically with this, serves to show us from Holley's example how largely the world's great enterprises are to-day in the hands of young men. Before the age of thirty-three Holley had practically grasped the steel-making secrets which have since changed the methods of trade and transportation, and have influenced all the arts and sciences that are built upon these two great foundations. Let us learn anew from the life of Holley, that though gray hairs are honorable, a great truth, or great discovery, or great work, is not the less worthy because youth is behind it, or at the bottom of it.

The only other thought regarding which I shall presume to add a word of comment is this : Holley's career well illustrates the broadened plane upon which men can in our day meet and study nature. In our modern life creeds and customs are chiefly valued in proportion as we are content to accept them at second hand. A mind like Holley's has little need of creeds, because it is one of the makers of customs for mankind. Living as he did close to the universal heart of nature and read-

ing her secrets as in a half-opened book, it was one of the privileges of Holley's genius to show us that there is in nature a beauty which even art cannot portray, because in this beauty are embodied the forces which make art possible.

With your permission I should like to conclude this thought by reading a few lines, the idea or suggestion of which, singularly enough, dates from a commemorative gathering, at which Alexander Lyman Holley was the moving spirit. Let me entitle it

THE NEW NATURE.

In the old days
Men walked with Nature in the quiet wood,
And found her features beautiful or good,
As were their ways.

Still do they look,
Painter and poet, seer and holy man,
For Nature's self, to find her where they can,—
In field or brook.

But these new days
Ofttimes entice from breezy dale and down
Her wandering feet into the dingy town,
Where chimneys blaze.

Are forge and flue,
Steeple and street, becoming in her sight
More dear than all the joys of day or night,
That once she knew ?

That—none may know ;
Her gifts are hers, to spend them as she will—
Changed, or the same, Nature is Nature still
And chooseth so.

Of all who seem
To seek her face, one asks, whom do her eyes
Rest kindliest on ? Nature herself replies
(So we may deem),

To him that asks :
"The wine is given to him that hath the cup ;
Use is but beauty, girded strongly up
For kindred tasks."

MR. ALBERT H. EMERY : So much has been said that it would seem needless to add anything further ; yet I should do great

violence to my feelings if, when the opportunity is offered, I should neglect to add at least a word towards giving them expression.

In the construction of the testing-machine, with which my name is identified, Mr. Holley was always ready to listen to my suggestions, and always ready to carry them out, and when the machine was finished he was the first to undertake to put its merits before the public. Unasked by me, he wrote and published at his own expense a little pamphlet, which he read before the Society of Mining Engineers, at their meeting at Baltimore. He was one of the first to recommend Congress to pay me for the machine, and he has done much more than I can tell you to put its merits before the public.

Last summer, just before he started for Europe, I walked into his office one morning. He said, "Emery, I am glad to see you. I am going to Europe, and I want to know if you will allow me to go to some of the European governments this summer and put that testing-machine before them and get some contracts for you?" I said, "Some other time, Mr. Holley; but not now." I was so situated, pecuniarily, at the time, owing to the Government not having paid me as recommended, that I did not care to have him do what he proposed then. But he seemed very anxious to put that machine before those governments. It was a work near his heart, and although he served on that Board a good many days of toil, he gave his valuable time to the public without a dollar of compensation, and when the Board was disbanded it went to his heart more than any other thing I ever heard him speak of. He spoke of it repeatedly, and with a great deal of feeling. He seemed deeply to regret that the Board could not be continued, and he go on with the others in the work which he had seen inaugurated. He has done more for me than I can tell you, and I would like to say a word in regard to this memorial which is proposed for him. It seems to me that the best monument of him is his own work. Mr. Holley has left a great monument, which must endure for all time. But as a member of this Society, and sister Societies with which he was connected, as an American engineer, as one of those engineers with whom he was associated in a profession which he has done more to lift up abroad, than any other man, as a citizen of this country, the wealth of which he has done so much to increase, I say much is due to Holley. I say

it advisedly. None of us, I believe, realize to what extent—millions of dollars—hundreds of millions of dollars,—nay, I think, if a careful estimate was made, thousands of millions of dollars would be found to have been added to the wealth of this country—to its industries, because of the progress of Bessemer steel, which has given us that permanent way which enables us to take our wheat from the Far West and lay it down in the centre of Europe. Without that steel we could not have done this. Without it those millions which have flowed into this country for the last three or four years would not have so flowed. Without it we would not have had this flood of commercial prosperity. To Holley's individual efforts much of this prosperity is due; and I, for one, shall be dissatisfied if this Society, if the other two engineering Societies, if those great Bessemer steel interests, which he has helped to build up, if this great prosperous country, which he has helped to make wealthy, do not unite in raising a monument worthy of one who has done so much for the world. I hope a monument may be put up which will be worthy of this country, worthy of these Societies, and worthy of Holley.

Mr. Partridge: Listening to all that has been said this afternoon, one who knew Mr. Holley only a little and at a distance, as it were, finds the single note recurring over and over again,—disinterested helpfulness. It seemed as though he had lifted everybody's load; and I think I can do little better than to give an instance of the way he would exercise his wonderful inventive ability to do even a little thing. When he wanted to make the Bessemer process known to the students—known to the world, I received through a friend a little card saying that in Hoboken, at such a time, there would be a lecture, by A. L. Holley, on the Bessemer process. I went there and found a lecture-room arranged somewhat like this, with a goodly audience, and a quiet, pleasant man came on the stage at one side. The whole front was filled with a great screen for the lantern, and that pleasant man commenced reading a delightful story of steel and its uses, and began with the details of the Bessemer process, and referred to Figure 1, and the lights went down, and while his voice went on continuously, the lantern flashed out, with a 15-foot diagram of Figure 1; and as he referred to letter after letter, or part after part, the black line of the pointer touched each one in succession.

We had to look and to listen. It went on, and Figure 2 was necessary, and, without a pause, 2, 3, 4, and it went on to 7, 8, 9, and 10, and they made their appearance in their regular order, and every part that the lecturer mentioned was touched by that needle-like shadow. It was teaching in its highest form. Only once in the whole lecture did Holley stop, and that was when, after referring backward to Figure 2, and forward to Figure 7, he turned round to see whether the man at the lantern was still keeping up the diagrams in order. There was not a hitch from the beginning to the end of the lecture. It was like magic. It was a system of illustrative lecturing so superior to anything that I had ever seen before, or ever heard of, that I thought it was enough to have made an ordinary lecturer's fortune, and all to enable the student to understand easily the Bessemer process.

Mr. Sellers: I would like to ask if the Hon. Mr. Wayne McVeagh is here.

The President: Is Mr. McVeagh here?

Mr. Sellers: A few days ago, I met him and told him of this memorial meeting, and he bowed his head with sorrow for his friend. He said that he would try to be here; that nothing would give him so much pleasure as to say a few words about one whom he valued so highly, not only as a personal friend, but as a man who had done so much for the industrial welfare of the country. If Mr. McVeagh is not here, I should like at least that there may be a record of what he wished to say.

LX.

DETERMINATION OF HEATING SURFACE REQUIRED IN VENTILATING FLUES.

BY

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The proper ventilation of a room requires the frequent removal of the vitiated air and the introduction of fresh air, the quantities by weight of the air ejected and the air introduced being equal. If the process be continuous and the proper

amount of air be admitted and removed every hour, or minute, the only other requirements are that the entering air shall be pure, that it shall be properly warmed in cold weather, either before it enters the room or by the mixture of warm and cold air in the room, and that the introduction and removal of air shall take place by gentle or inappreciable currents, distributed in such a manner that the pure air may be thoroughly diffused throughout the room before it is removed.

These simple rules are easily stated and comprehended. It is also well understood that the movement of air requires force in proportion to the mass moved and the velocity which is imparted to it. The problems which arise in ventilation consist mainly in determining the positions, arrangements, and sizes of the passages through which the air enters and leaves the space ventilated, and the adaptation to the passages or flues of the force or forces which produce the movement of the air. On the solution of these problems, too often misapplied or misunderstood, successful ventilation depends.

The various means of producing the movement of the air are:

1st. *Fans or blowers*, requiring the use of machinery in driving them.

2d. *Ventilating chimneys*, in which the movement of the air is caused by the difference in weight between the columns of hot air in the flue and the cooler air outside. This requires necessarily that the air in the flue shall be warmer than that outside, and the necessary heat must be imparted to the air before it enters the flue.

3d. The movement of the air may be produced by *steam jets* in the flue, the particles of steam issuing at a high velocity, carrying with them particles of air, and thus producing a diminution of pressure below the jet and a consequent movement.

The steam jet method is seldom used, the ventilating flues being generally employed. The most common application of the latter is the ordinary ventilating flues of dwelling-houses. In this case reliance is usually placed upon the heated air of the room, which, finding its way into the flues, forms a vertical column lighter than the outer air, and having a height equal to the height of the flues. An upward movement in the flues is thus produced.

The laws of the movement, involving the height of the flues, the temperature of the air in the room, the temperature of the outer air, and the velocity of the upward current, may in this case be theoretically determined; and from such a determination, taking into account the frictional resistances, the area of the cross-section of a flue for the discharge of a given weight of air may be ascertained. Analytical investigations of this character are seldom made except by experts, and for ordinary dwelling-houses the whole system is generally a hap-hazard construction, in which the errors are quite certain to fall on the side of inefficient ventilation. Moreover the system cannot operate during those periods of the year in which the temperature of the outer air is the same or nearly the same as that of the room. During these seasons some other means must be resorted to in order to warm the air before it enters the vertical ventilating flues. The system is inefficient also, except with very large flues, owing to the slight difference, even in ordinary cold weather, between the temperature of the air in the room and that of the air outside.

For very active ventilation, therefore, with such flues as may ordinarily be constructed, the air must be heated; and this may be done by several methods:

1st. By a stove at the base of the flue, the stove-chimney passing up through the flue.

2d. By gas-jets burning at the base.

3d. By coils of steam-pipes in a chamber at the base of the flue.

All of these processes require careful analysis in their application, and may, to a certain extent, be subjected to such an analysis. The object of this paper is to investigate the laws which govern the ventilation when the air is heated by means of coils of steam pipe, before it enters the flue. These laws have not heretofore been developed, and as this system of ventilation is a very simple one, capable of extended application, it is hoped that the following analysis may at least lead to a full discussion of the subject.

Let it be supposed that the air in the room is to be renewed at the rate of W pounds per second. The volume of this quantity of air can easily be determined when its temperature is given. Suppose also that it is to be ejected through a vertical flue whose cross-section is A and whose height is H, and

that it is to be heated by steam-coils at the base of the flue, having a total exterior surface equal to S.

The following notation will be used :

W = weight of air discharged per second.

H = height of flue.

S = the exterior surface of steam-coil.

A = area of cross-section of flue.

T_a = the absolute temperature of the external air, *i. e.*, the common temperature Fahrenheit + 459.4°.

T_c = the absolute temperature of the air in the flue.

T_s = the temperature of the steam in the coils.

D_a = the weight of a cubic foot of the external air.

D_c = the weight of a cubic foot of the air in the flue.

V = the theoretical velocity of the air in the flue.

V' = its actual velocity when frictional resistances are taken into account.

r = the rate in units of heat per hour for each square foot of the surface S, at which the air receives heat from the coil, and for each degree of difference between the temperature of the steam and the air of the room.

K = a coefficient of velocity, such that $KV = V'$.

p = the unbalanced upward pressure at the base of the flue due to the difference between D_a and D_c, or due to the difference in weight between the two volumes of the height H within and outside of the flue.

The pressure per square foot, p, will then be represented by the equation,

$$p = HD_a - HD_c \text{ or } p = H(D_a - D_c) \quad . \quad . \quad . \quad . \quad (1.)$$

This pressure may be represented by the weight of a column of the heated air, represented by

$$\frac{p}{D_a} = H\left(\frac{D_a - D_c}{D_c}\right) \quad . \quad . \quad . \quad . \quad . \quad (2.)$$

The velocity with which the air would flow through the flue if there were no resistances would be determined by the expression,

$$\frac{V^2}{2g} = H\left(\frac{D_a - D_c}{D_c}\right)$$

$$V = \sqrt{2gH\left(\frac{D_a - D_c}{D_c}\right)} \quad . \quad . \quad . \quad . \quad . \quad (3.)$$

But from the Mariotte-Gay Lussac law for air,

$$\frac{D_c}{D_a} = \frac{T_a}{T_c} \text{ or } D_c = D_a\left(\frac{T_a}{T_c}\right)$$

Substituting this value of D_c in equation (3), there results

$$V' = \sqrt{2gH\left(\frac{T_c - T_a}{T_a}\right)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4.)$$

In this expression the theoretical velocity is expressed in terms of the absolute temperatures of the air within and without the flue, and the height of the flue.

From (4) we obtain

$$T_c - T_a = \frac{V'^2}{2gH} \cdot T_a \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5.)$$

The quantity of heat transferred to the air on its passage through or among the steam-pipes may be represented by

$$Q = WC(T_c - T_a) \quad . \quad . \quad . \quad . \quad . \quad . \quad (6.)$$

in which $C = .238$, the specific heat of air at constant pressure.

All of the above formulas are well known; the following are believed to be new:

The quantity of heat imparted per second to the air by the steam-pipes may be represented by the total exterior surface of the steam-pipes (S) expressed in square feet, multiplied by the rate per second and per square foot at which heat is transferred to the air, or

$$\frac{S_r(T_s - T_a)}{3600} = Q'$$

and from the nature of the problem we must have $Q = Q'$

or

$$\frac{S_r(T_s - T_a)}{3600} = WC(T_c - T_a) \quad . \quad . \quad . \quad . \quad . \quad (7.)$$

from which we obtain

$$T_c - T_a = \frac{S_r(T_s - T_a)}{WC \times 3600} \quad . \quad . \quad . \quad . \quad . \quad (8.)$$

Combining this equation with equation (5) we have

$$\frac{S_r(T_s - T_a)}{WC \times 3600} = \frac{V'^2}{2gH} \times T_a$$

and

$$S = \frac{V'^2}{2gH} \times \frac{WCT_a}{\frac{{}_r(T_s - T_a)}{3600}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (9.)$$

This expression gives the total heating surface of the steam-pipes in terms of the velocity, the height of the flue, the weight of air discharged per second, and the absolute temperature of the external air.

If we substitute for V' its value KV, the expression becomes

$$S = \frac{K^2 V^3 \times W C T_a}{2gH\left(\frac{r(T_s - T_a)}{3600}\right)} \quad . \quad . \quad . \quad . \quad (10.)$$

and since V is the actual velocity, we have

$$W = D_c V A$$

$$\therefore S = \frac{K^2 V^3 \times D_c C T_a A}{2gH\left(\frac{r(T_s - T_a)}{3600}\right)} \quad . \quad . \quad . \quad (11.)$$

A being the area or cross-section of the flue. Equations (10) and (11) represent the laws connecting the heating surface with the height of the chimney, the area of the flue, and the temperature of the external air. They show that the heating surface is directly proportional to the cube of the velocity, to the area of the flue, and to the temperature of the external air, and inversely proportional to the height of the chimney and the rate of transfer of the heat, r or $r\,(T_s - T_a)$.

To illustrate the practical use of the formula, let it be proposed to renew the air of a room containing 50,000 cubic feet four times in an hour, through a flue whose cross-section $A = 12$ square feet, the height (H) being 50 feet. Required the number of square feet in the surface of the coil, the steam within the coil being maintained at 50 pounds pressure. Suppose, further, that the temperature of the air, before it enters the flue, is 60° F., the same as that of the outside air.

The weight of a cubic foot of air at 60° F., or (D_a), is found as follows: The weight of a cubic foot of air at 32° F., and atmospheric pressure being known, viz., 0.0808 pound, the weight at 60° F., will be

$$D_a = 0.0808 \frac{T_c}{T_a}$$

T_c being the absolute temperature corresponding to 32° F. (or 32° + 459.4° = 491.4°), and T_a being equal to 60° + 459.4° = 519.4°,

$$\therefore D_a = 0.0808 \frac{491.4}{519.4} = 0.0764 \text{ lbs.}$$

and the weight of 50,000 cubic feet at 60° F. will be

$$50000 \times 0.0764 = 3820 \text{ lbs.}$$

As four times this weight is to pass through the flue in one hour, we have

$$3,820 \times 4 = 15280 \text{ lbs. per hour ;}$$
$$\text{or } 254.67 \text{ lbs. per minute ;}$$
$$\text{or } 4.244 \text{ lbs. per second.}$$
$$\therefore W = 4.244 \text{ lbs.}$$

We also have

$$T_a = 519.4^\circ$$
$$C = 0.238$$

For the value of r to be used in the formula, and average of the results of the experiments made by Mr. C. B. Richards, at the Colt's Arms Co., at Hartford, may be taken for ordinary forms of heaters, it being understood that this value is assumed to be nearly correct, although the quantity (r) was found to vary in proportion to the quantity of air passing through the heater in a given time. Assuming the value of (r) to be 2.5 units of heat per hour per square foot of surface, and for each degree difference of temperature between the steam in the coil and the air of the room, there results for the value of r per second,

$$\frac{r}{3600} \times (T_s - T_a)$$

with steam at 50 pounds,

$$T_s - T_a = 281^\circ - 60^\circ = 221^\circ \text{ F.}$$

$$\therefore \frac{r}{3600}(T_s - T_a) = \frac{2.5}{3600} \times 221 = 0.153$$

All the quantities in equation (10) are now known for this problem, except $K^2 V^2$. If we assume a velocity V, and also a correct value of K, the resultant value of S should be such as to give this velocity. Assuming $V = 7$ feet per second, and $K = 4$, the value of $K^2 V^2$ will be $16 \times 49 = 784$.

In regard to the value of K, Peclet found in the ordinary boiler chimney of manufacturing establishments, for heights of 10, 20, and 30 meters, V' equal respectively to $5.6\ V$, $6\ V$, and $6.3\ V$. It may also be demonstrated that if the resistances were due to friction alone, the loss of velocity in a simple rectangular flue, 50 feet high and 12 square feet cross-section, would be such that V' would be about twice V, or $V' = 2\ V$.

The interposition of the coil of pipe through which the air

passes increases the resistance beyond that of the simple flue, but it cannot be so great as that developed in passing through the grate, flues, and chimney of a steam-boiler.

I have taken for this example $V' = 4V$, *i.e.*, the actual velocity equal only to one-fourth of the theoretical, which will at least throw the error, if there be any, on the side of excess in the value of S.

We may now recapitulate the values of the quantities in equation (10) as determined for this problem.

$$K^2 V^2 = 784.$$

$$\frac{r(T_s - T_a)}{3600} = 0.153$$

$$W = 4.244.$$

$$C = 0.238.$$

$$T_a = 519.4°.$$

$$\therefore S = \frac{K^2 V^2 \times WCT_a}{2gH. \frac{r(T_s - T_a)}{3600}} = 835 \text{ square feet.}$$

It now remains to ascertain what temperature and density the air in the flue will have.

The quantity of heat expended per second will be:

$$S \cdot \frac{r(T_s - T_a)}{3600} = S \times 0.153 = 835 \times 0.153 = 127.755 \text{ units.}$$

Per minute it will be 7,665.30, and per hour, 459,918 units.

To find the flue temperature (T) we have

$$Q = (WCT_c - T_a)$$

$$\text{or } T_a = \frac{Q + WCT_a}{WC} = \frac{127.755 + 1.01 \times 519.4}{1.01} = 645.9°,$$

corresponding to a thermometric temperature of 645.9 − 459.4 = 186.5°. This is the temperature of the air in the flue. Its density will be

$$D_c = 0.0808 \frac{T_c}{645.9} = 0.0808 \frac{491.4}{645.9} = 0.0614 \text{ lbs. per cubic foot.}$$

The volume of one pound will be $\frac{1}{0.0617} = 16.28$ cubic feet.

With a velocity of 7 feet per second there will be ejected through the flue of 12 square-feet area, 302,400 cubic feet, or 302,400 × 0.0617 = 18,567.36 pounds per hour.

This is in excess of the requirement, which was only 15,280 pounds per hour.

If we assume a velocity of 5 feet per second, the discharge of heated air will be $12 \times 5 \times 3600 = 216{,}000$ cubic feet per hour. The resistance to the flow will be diminished nearly in proportion to the square of the velocities, and we shall have $K^2 V^2 = 9 \times 25 = 225$. The value of r will also be somewhat diminished, and may be taken as 2, so that $r \dfrac{T_c - T_a}{3600} = 0.123$.

$$\therefore S = \frac{225 \times 4.244 \times 0.238 \times 519.4}{64.4 \times 50 \times 0.123} = 297. \text{ square feet.}$$

The heat expended per second will be $297 \times .123 = 36.53$ units per second, 2191.8 per minute, 131508. per hour.

$$T_c = \frac{36.53 + 1.01 \times 519.4}{1.01} = 555.5^\circ = 96^\circ \text{ F.}$$

$$D_c = 0.0808 \times \frac{491.4}{555.5} = .0719.$$

The theoretical velocity in the last case will be

$$V = \sqrt{2g \times 50 \left(\frac{555. - 519.4}{519.4}\right)} = 15 \text{ feet per second;}$$

i.e., three times the actual velocity, which was assumed to be 5 feet.

The weight of air discharged will be $216000 \times 0.0719 = 15530$ pounds per hour, only slightly in excess of the quantity required, which was 15280 pounds.

It will be seen that the quantity K^2, the coefficient of the square of the velocity, and in regard to which the most uncertainty exists, has an important influence on the quantity S. It seems probable that a value of K between 3 and 4, or of K^2 between 9 and 16, will answer for all ordinary cases, and that a value of r between 2 and 2.5 will be approximately near enough. The smaller values correspond to low velocities and large flues, and the larger values to high velocities and smaller flues.

If the value of V be assumed as 5 feet per second, and that of K as 3, or K^2 as 9, then by combining the constants in equation (10) we may write approximately,

$$S = 1500.\frac{W T_a}{H(T_c - T_a)}$$

and for the area of the cross section of the flue or flues for a given discharge (W) we have

$$A = \frac{W}{D_c V}$$

in which V, the velocity, is 5 feet per second.

These last equations are suggested as working formulæ under ordinary circumstances. Further experiments are desirable for ascertaining the values of K and r under ordinary conditions of the problem; still the formulæ, while only approximately correct, exhibit the laws which control the movements of the air.

To compare this method of ventilation with that by means of a fan or blower, let it be supposed, as found in the last example, that the heating surface required is, in round numbers, 300 square feet. The quantity of heat transferred per second would be 300×0.123 nearly, or about 36.9 units of heat; per hour, 132840 units. If we estimate in round numbers about 1100 units to raise the temperature of water from 60° and evaporate it at 281°, corresponding to 50 pounds pressure, we shall have $\frac{132840}{1100} = 120.7$ pounds of water necessary to produce this amount of heat. Estimating 1 horse-power per hour at 40 pounds of water evaporated under the same conditions, the heat expended for ventilation would furnish in an engine about 3 horse-power.

Compared with the estimates of the horse-power required for a Sturtevant blower to produce the same effect, the steam-coils are more economical than the blowers. There seems to be no doubt that steam-coils properly devised and adapted to chimneys or flues will give more efficient ventilation than the blower, for less cost of construction and maintenance.

A more extended discussion of this subject might be given, especially with reference to the constants in the equations; but the object of this paper is merely to open the discussion of the subject and to point out the correct method of treating the problem.

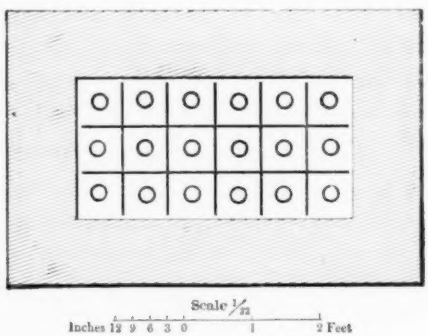
The arrangement of the steam pipes in such a manner that the greatest amount of heat will be transferred to the air with the least resistance to its motion, is a matter of importance. It is desirable, if possible, to place these pipes within the flues, and it is a difficult matter to introduce the requisite

amount of heating surface, if dependence is placed solely on the direct contact of the air with the steam-pipes.

The following plan is suggested for overcoming the difficulty. It has not, as far as I am aware, been heretofore practiced. Vertical pipes, which are to contain live steam, are introduced into the flue, extending five, ten, or twelve feet upward in the flue. These are separated by sheet-iron diaphragms, which receive heat from the steam-pipes by direct radiation.

The flue is thus divided into several smaller flues at its base, the whole surface of these smaller flues, as well as the walls of the main flue, acting as heating surface. Air does not receive heat by radiation, but, on the other hand, it does not obstruct the radiation of heat.

The figure below (Fig. 2) shows how a large amount of actual



Cross-section of Flue.

Fig. 2.

heating surface with a minimum amount of steam-pipe may be introduced into the base of a flue. In this case the flue has a cross-section of eight square feet, and it contains eighteen vertical steam-pipes, each 2 inches in diameter and 12 feet long, the pipes being closed at the top with suitable air-valves.

By means of the diaphragms shown, the actual heating surface with which the air comes in contact, is as follows: for each foot in height (of the 12 feet) of flue occupied by the pipes.

For the steam-pipes, $\frac{6}{12} \times 18 = 9$ square feet.

For the walls of the diaphragms, including the flue walls, $2'.66 \times 18'. = 47'.88$ square feet.

Total per foot height, . . .	56.88 square feet.
Total for twelve feet high, . . .	682.56 "

Thus, for a total exterior surface of steam-pipes of 108 square feet, an actual efficient surface for heating the air is obtained of 682.56 square feet.

This surface may not all be as efficient as the surface of the pipes, but when it is considered that steam-pipes can give off heat by radiation without losing very sensibly their efficiency of heating air by contact under the conditions here given, it is evident that the surplus surface obtained by the diaphragms ought to compensate for the diminution of active pipe surface. Experiments alone will determine this question, but there seems to be no scientific reason why the device should not be effective.

In this case it will not be difficult to determine the coefficient of velocity K by actual calculation from known data.

Discussion.

A Member: Some years ago it was very customary to ventilate mines by shafts with heating furnaces at the bottom. That principle has been superseded by fans driven by engines, and it seems to me the paper just read subverts that theory, and would suggest the wisdom of going back to earlier and abandoned practice.

Professor Hutton: I think it only fair to state, in discussing that question, that a calculation by this system where the coil is at the base, and the draft depends on the height of the column, would be different from what would exist if you were calculating a suction fan for ventilating purposes. It is in a comparison with the fans for *forcing* as applied for mining purposes,—that is, where we attempt to force the air up the column by a fan at the bottom,—that we should find this great relative efficiency for the coil. If we could put the exhaust arrangement at the roof of a building, I think we would find less difference in favor of the coil.

It simply refers to a case where it is not practicable to have machinery up towards the roof; but where the fresh air must be forced in by the forcing system, that this comparison seems to be fair.

LXI.

EFFICIENCY OF TURBINES AS AFFECTED BY FORM OF GATE.

BY

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THE accompanying tables and diagrams are presented to show the different results produced by two different turbine wheels, of essentially the same form of bucket, and due to the mode of delivering the water to the wheel.

Both wheels are of the class known as inward and downward discharge, but in the case of the National wheel, the chutes or passages are formed in groups of four, and one passage of each group is closed entirely by the same operation, leaving the others entirely unobstructed until all are successively closed or opened by four movements of the gate.

In the Burnham wheel, the water is partially cut off from every passage at the same time, and the result is, as is also shown in the Fourneyron, and various other wheels, that the first partial closure, say to seven-eighths of the gate opening, makes very little difference in the amount of water passing the wheel, while, when the gate is only one-fourth opened, nearly one-half the whole amount of water passes through the gate.

This effect is noticeable in all the turbines, whether cylinder or register gate, in which the passage of the water is cut off by a sharp edge, leaving an angle behind it, in which the entering water can form an eddy, and thus break the full force of the uniform blow, which seems to be essential to good results in any form of turbine.

This effect of throttling the water with an edged gate, has long been known to the builders of turbines, and has led to various devices for diminishing the quantity of water delivered to the wheel, while at the same time maintaining a smooth and unbroken current.

The hinged gate of the Leffel, and other wheels, is one of the most common devices, and answers its purpose very well, the great objection to it being its liability to leakage from wear of joints and hinges.

The Swain and Risdon wheels, have cylinder gates with an outside garniture attached, which prevents the current from being abruptly broken, and have both attained very high results at partial gate, and the bucket of the Swain wheel may be considered as the type which has been generally followed, with some variations, in all the later turbines which have proved of any value.

Figure 4 shows the efficiency of a group of wheels when the water is cut off by a sharp edge, and Diagram 5 of a group in which the water passage has been preserved without a sharp cut-off, as far as possible, and the gates, whether cylinder or register, so arranged as to maintain a smooth volume of water directly to the opening of the buckets, while gradually diminishing its quantity as the gates are closed, and the results in efficiency at part gate, are very noticeable on comparison of the two diagrams.

Test of Burnham "Standard" Turbine, 54 inch diameter, at Works of Douglass Axe Co., September 17th, 1881. Brake circle, 50 Feet in Circumference. Cubic feet of Water Corrected per Velocity of Approach. Weir 12 feet long.

Fall Gate.	Weight in scale.	No of Rev.	Rev. per min.	Head on wheel.	Head on weir.	Cubic ft. water per min.	Horse Power water.	Horse Power wheel.	Per cent. effect.
1	450	250	77.72	10.063	1.268	3417.05	64.95	53.	.8160
2	480	"	75.77	10.035	1.274	3441.56	65.23	55.10	.8447
3	500	"	73.17	10.03	1.283	3477.80	65.89	55.43	.8413
4	530	"	68.8	10.	1.284	3481.73	65.77	55.25	.9420
5	550	"	64.65	9.97	1.292	3514.12	66.18	53.88	.8142
⅞ Gate.									
6	400	"	81.52	10.06	1.220	3228.15	61.31	49.40	.8053
7	450	"	76.14	10.02	1.288	3288.46	62.24	51.91	.8353
8	480	"	73.	10.01	1.245	3322.68	62.92	53.09	.8440
9	500	"	71.09	10.	1.249	3342.06	63.13	53.86	.8532
¾ Gate.									
10	400	"	73.89	10.07	1.166	3018.07	57.41	44.78	.7800
11	430	"	69.77	10.08	1.175	3053.81	58.14	45.45	.7817
12	380	"	76.72	10.11	1.156	2980.57	56.92	43.87	.7707
⅝ Gate.									
13	300	"	78.74	10.205	1.078	2674.31	51.55	35.79	.6943
14	330	"	74.25	10.19	1.085	2700.70	51.98	37.13	.7143
15	350	"	70.75	10.18	1.094	2733.46	52.56	37.50	.7135
½ Gate.									
16	250	"	75	10.315	.988	2350.81	45.80	28.41	.6203
17	270	"	66.09	10.30	.994	2371.69	46.14	27.04	.5860
¼ Gate.									
18	150	"	68.18	10.54	.796	1697.14	33.71	15.50	.4598
19	120	"	74.62	10.56	.786	1664.86	33.71	13.37	.4440

Test of "National" Turbine, 50 × 15 inches, at Douglass Axe Co.'s Shops, September 8th, 1881. Brake circle, 50 feet in circumference. Cubic feet of Water Corrected per Velocity of Approach. Weir, 15 feet long.

Fall Gate.	Weight on scale.	No. of Rev.	Rev. per min.	Head on wheel.	Head on weir.	Cubic ft. water per min.	Horse Power water.	Horse Power wheel.	Per cent. effect.
1	450	500	85.23	10.54	1.096	3669.53	72.77	58.11	.7985
2	400	"	93.75	10.52	1.1066	3719.51	73.62	56.82	.7718
3	500	"	78.53	10.48	"	"	73.34	59.50	.8111
4	480	"	80.86	10.44	1.104	3709.39	72.78	58.81	.8080
5	550	"	70.47	10.40	1.124	3809.81	74.56	58.68	.7872
6	530	"	67.63	10.41	1.129	3835.66	75.14	59.93	.7977
¾ Gate.									
7	400	"	73.71	10.72	.947	2952.92	59.56	44.67	.7500
8	380	"	77.32	10.57	"	"	58.73	44.52	.7581
9	390	"	75.95	10.56	.953	2980.69	59.21	44.88	.7579
½ Gate.									
10	250	"	74.257	10.807	.747	2065.21	41.99	28.13	.6698
11	240	"	76.53	"	.741	2040.43	41.49	27.84	.6710
¼ Gate.									
12	120	250	67.57	11.56	.4915	1100.18	23.93	12.28	.5132
13	100	250	74.534	"	.492	1101.87	23.97	11.29	.4710

LXII.

THE APPOINTMENT OF A UNITED STATES GOVERNMENT COMMISSION OF TESTS OF METALS, AND CONSTRUCTIVE MATERIALS.

BY

THOMAS EGLESTON, PH.D., NEW YORK CITY.

At a Convention of the Society of Civil Engineers, held June 4th, 1872, in Chicago, it was resolved to ask the United States Government for a commission to test iron and steel and other metals, with a view of ascertaining their properties, as the tables of constants which had been used for a long time in calculating the strength of metals were found to be either inaccurate or in some instances inapplicable to the cases now existing, and their use known to have caused a number of disasters which had resulted in the serious loss of property and life. On March 4th, 1875, Congress granted the prayer of the Society of Civil Engineers and created a commission of seven members, to be appointed by the President of the United States, to test iron and steel and other metals, and appropriated $75,000 for this purpose. It was understood at the time

Comparative Te

Diagram A.

at T

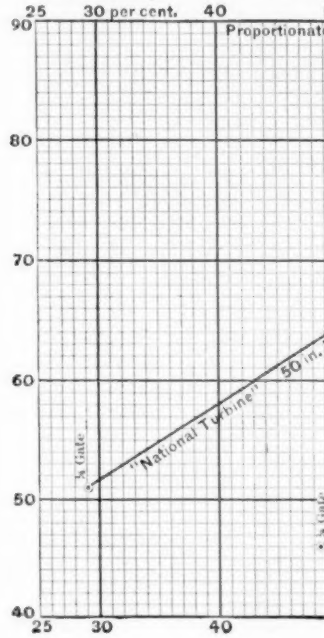


FIG. 3.

Diagram B.

Proportion of Power of Water

Realized by Wheels where Water Passage is Cut off by sharp edge of gate.

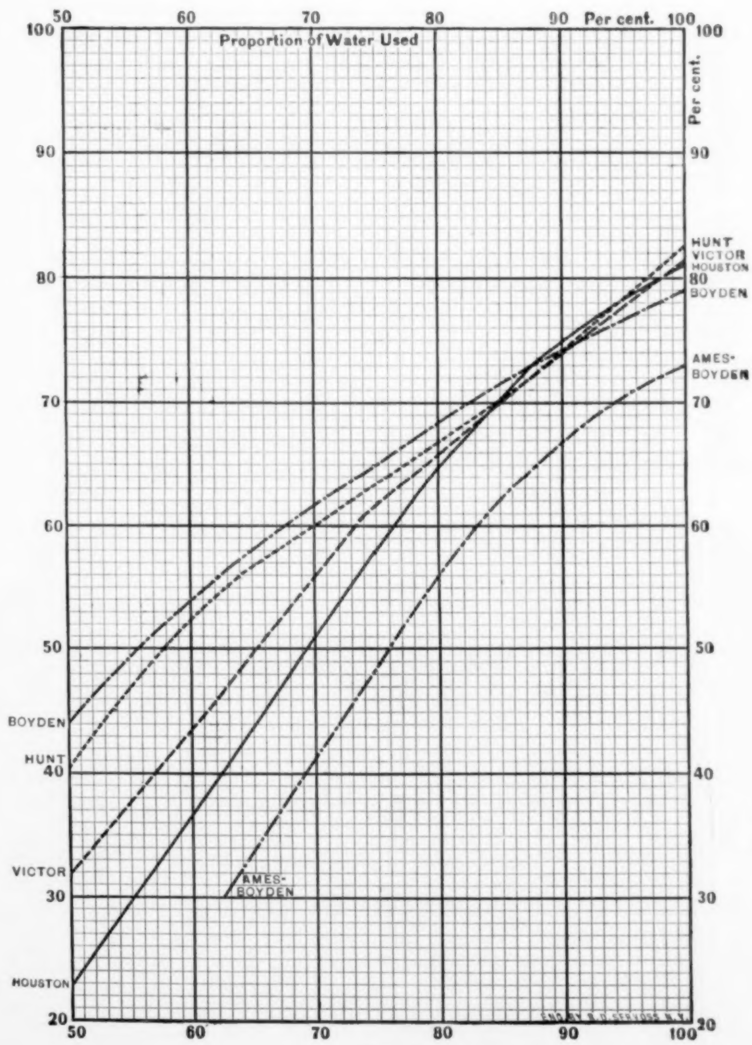


FIG. 4.

N

e Tests of "National" & Burnham Turbines,

at Douglas Axe Co's Shops; Sept. 1881. Sam. Webber

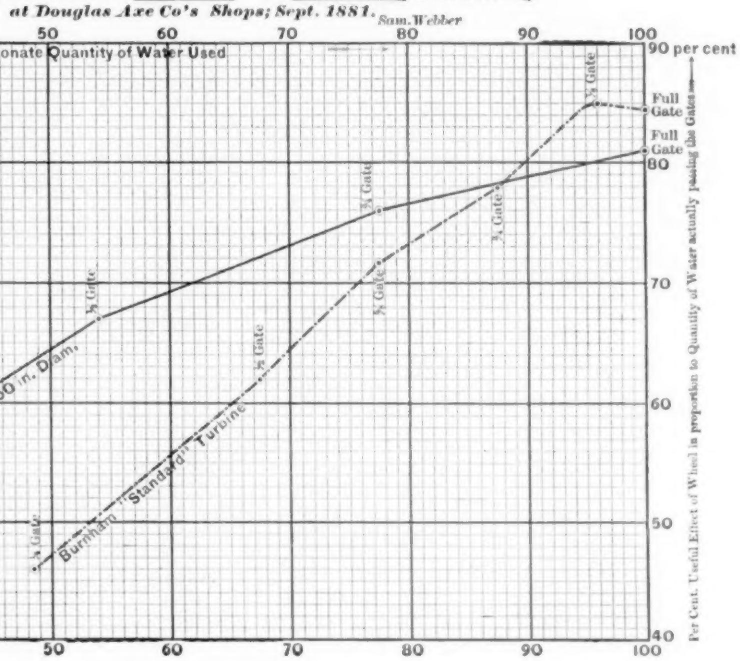


Diagram C.

Proportion of Power of Water

Realized by Wheels having Unbroken Water Passages or Chutes.

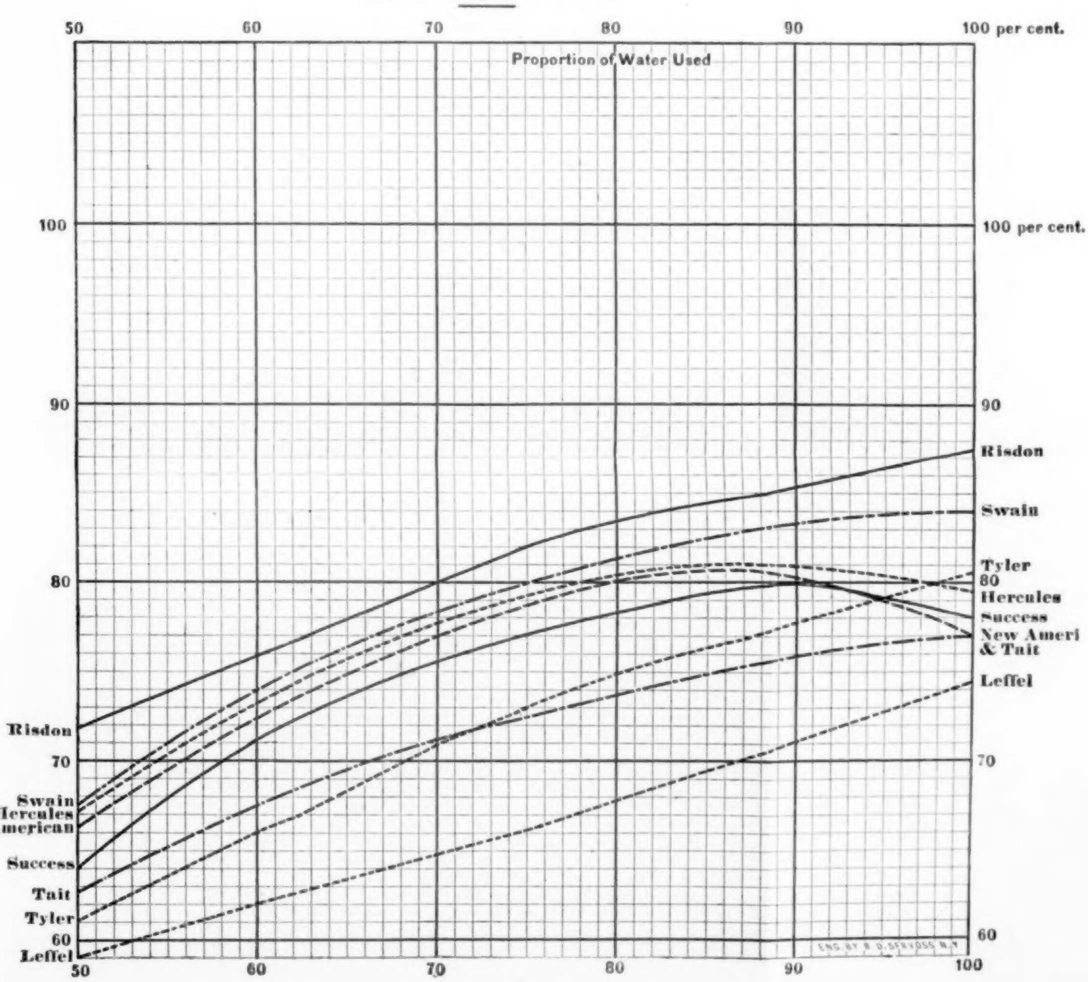


FIG. 5

be the most remarkable machine of this kind that has ever been constructed, the result of the work on which has been to revolutionize most of our ideas upon the methods of testing the metals. They made one hundred and fifty analyses of iron and steel; they examined the methods of producing chain cables, reported upon the relations and conditions of certain alloys of copper, and caused to be made a large number of compounds, to investigate the effects of varying proportions of the ingredients usually found in the metals and alloys in common use, many of which, though made at great expense, have never been studied, for the board was legislated out of existence before they had time to use the testing-machine to any extent or to examine any very large number of the alloys and compounds, which had been manufactured for them with great liberality by many of the best manufacturers in the country, at a large expenditure both of time and money. Some of their work has been published, but it is very difficult to get the reports, which should be reprinted; some of it, it is feared, is already lost, and must be done over again if we are to have it at all, or know which of the compounds or alloys have no present value.

The testing-machine has, by law, been allowed to be used by private parties, and a very large amount of material has already been tested upon it by them, it being kept almost constantly employed by engineers of companies who wish to test their material before they use it. But while this machine is the most accurate one that has ever been built, it is very expensive to use it, costing nearly twenty-five dollars a day, but after the work is done, it is not only extremely accurate but all the work done on it at any time can be compared with any other work done at any previous period, a condition of things which up to this time has never existed. If the work of the commission had produced no other result than to prove that reliable and comparable data could only be obtained on full-sized pieces, and that other testing-machines constructed to work on specimens of reduced area which have been used up to the present time, not only do not give comparable results, but that many of them, from faulty construction, are in themselves entirely unreliable, the board would have done all that could have been reasonably asked of it. If this machine, however, or any number of machines like it, is kept constantly in use by private parties, the public will not necessarily be any

the wiser for the work done, for the reason that although the expense of such investigations is much greater when done by private individuals than by a commission, these results will not usually be published, nor will the criticism of engineers generally be invited or obtained.

The work which is necessary to be done could not possibly have been accomplished in the short time in which this board was in existence, even supposing it had found the testing-machine constructed on the day it commenced to work. Such investigations can only be done with the greatest deliberation. It not only takes a great deal of time and thought to plan them, but it takes a longer time to ascertain what the results mean after the experiments have been made. It is, therefore, proposed that the new board shall publish the results monthly, but shall make no effort to draw any conclusions until, assisted by all engineers who are interested in these experiments, they have both been accumulated in sufficient numbers and have been criticised and discussed long enough to make their conclusions worthy of the acceptance of the engineering world.

It has wisely been said that no structure is stronger than its weakest part, and it very often happens that on account of defects in its manufacture, or a want of the knowledge which the work of such a board would give to the manufacturer, this weakest part may be crippled by strain, even before it is used. It may therefore be, and has very often been the case, that a single piece of defective material, whose defects should have been ascertained before it was used, has caused great disaster, and it should be one of the provinces of such a board as this to ascertain beforehand how such weakening may be discovered before the pieces are used.

It is necessary also that this board should examine not only the quality and the quantity of the metals which are used, but also their form. It does not follow that because we have been using certain forms for certain metals that these are of necessity the best; but the form in which the metal is used for commercial operations, every one knows, has the greatest possible influence not only upon its strength but also upon its durability. No better illustration can be given of the proper use of material than a rye straw. In its natural shape it will bear several ounces, if the weight is applied vertically, but if the same amount of material had been collected in a solid form,

the weight that it could possibly bear would be almost nothing. It does not follow at all that we have been of necessity using the best forms for our metals, but it is more than likely that we could use less weight in a different shape, and yet have the piece stronger. What we wish to arrive at in these investigations is not so much to know why a structure fails after it has failed, or to ascertain the cause of the falling of buildings and bridges after there has been a great destruction of life and property, but so to form and arrange the materials that we may be certain beforehand that the constructions will not fail, and that there will be no disaster.

To give some idea of the value of the researches of such a commission, I have extracted from the Report of the last Census a few items relating to the iron and steel industries of the United States, during the year 1880.

Amount of capital invested,	$230,971,884.00
Value of the materials used,	191,271,150.00
Value of the products,	296,557,685.00
Wages paid,	55,476,785.00
Number of hands employed,	140,985.00
Number of works producing,	1,005.00
Total production,	7,265,140 tons.

This amount of total production is divided as follows:

Pig-iron product,	3,781,021 tons.
Products of the rolling mills,	2,353,248 "
Bessemer steel,	889,896 "
Open-hearth steel,	93,143 "
Crucible steel,	70,319 "
Blister steel,	4,957 "
Blooms and bar iron from the ore,	37,633 "
Blooms from pig and scrap,	34,924 "

In the rail manufacture there were produced:

Iron rails,	466,917 tons.
Bessemer steel rails,	741,475 "
Open-hearth steel rails,	9,105 "
	1,217,497 "

Of structural irons, 96,810 tons were produced. There were used in the year 1881 for the construction of bridges 80,000 tons of iron and steel, representing fifty consecutive miles of structure, over which the public travel with such a

perfect feeling of security that they scarcely ever give a thought to the possibility of danger. Yet it not unfrequently happens that these structures give way, producing great disaster to life and property, which it is believed that the researches of a commission of this kind might prevent. Of very large beams used in the floors of buildings over 50,000 tons were used. Many of these were used in structures which were considered perfectly safe because they are what are termed "fire proof," and yet it is undoubtedly the case that the buildings are in many cases dangerous from the start, owing to the fact that there is a large amount of strain frequently tending to weaken and fatigue the structures in which we feel, and are perhaps, perfectly secure under ordinary conditions, but they often become really dangerous when we are least suspecting it. This feeling of security is sometimes startled by the giving way of some large structure, either from fatigue caused by overloading from its own material, or from overstraining or sudden shock. The falling in of some building at the time when it was subject to least strain, or the sudden giving way of structures subjected to fire at times when they should have stood for many hours, when all this is probably preventable, startles us and robs us of our feeling of security, and when we come to make the observations after the fact, we find that our data were unreliable, either because the material used was such as had not been contemplated in the formulæ, or for other causes which it is hoped the commission will make known and be able to prevent. The factors of safety used by engineers are taken from tables constructed many years ago by foreign engineers on materials made under entirely different processes from those now in use, and on metals manufactured abroad. We know hardly anything of these factors as applied to materials of American manufacture. We are using tables and formulæ which we are finding to our cost are only approximately reliable. It is becoming known to insurance companies that weight improperly distributed in structures is not only a source of danger against which *they* must protect themselves by charging a high premium, but that it is a source of actual money loss to the manufacturers. Instances are known where a redistribution of the weight of buildings has, with the same machinery, made an increase in output of over twenty-five per cent. possible.

There were produced in 1880, 1,218,000 tons of rails of all

kinds. Accidents from the use of rails are much less common now than they were in former years, owing to the much greater attention that is now paid to the condition of the roadbed, and it is the generally received opinion that rails need no other testing than that they receive from use in the track. Yet I have several times shown that under conditions nearly similar, one rail bore easily 80,000,000 tons of traffic, and was good for 80,000,000 tons more, while another of the same make was worn out and good for nothing, with less than that amount of traffic. It is a fact known to a few that the steel rails which are now being made are not much, if any better, than the best iron rails that were made in 1860. Those of us who are familiar with the present practice of working for the greatest possible output of the works think we are right in stating this as the reason why some of our best engineers see a possible return to iron rails in the near future, but why should not a large output of manufactured product be consistent with the greatest strength in the material? Is there not some very simple means by which the greatest product may be made of as good quality as the reduced one? These are questions which if a manufacturer answers at all he answers for himself and his neighbor, to whom the fact is unknown, or who cannot, or does not investigate, goes on producing a material, which if it is not a source of danger is at least a product inferior to what might have been made, and the world is a loser by just so much as a larger quantity of inferior material is made for use. What shall be said of that manufacturer who, knowing the defect, and the cure as well as the danger, refuses to cure it, and deliberately breaks a contract for the superior and safe material, and continues to make the inferior and perhaps dangerous one because he can sell it? The Pennsylvania Railroad is a remarkable instance of judgment and management in this matter, for they have shown and proved that the large expenditure which they make in the examination of all the materials which they use in their various structures and machines, is fully justified by the results which they have obtained. A smaller corporation, having just as much at stake, so far as its own security goes, might not be able to make these examinations, and must either wait until it can follow the precedents of the larger one, or in some other way obtain a knowledge of these results, or it must run the risk by not having them, of endangering the property

of those who are interested in them or perhaps the lives of those who use them. As the large majority of corporations are in just such conditions they must either go without or look to the government for such knowledge.

Notwithstanding an amount of study, which has certainly been large, made by private corporations, and others in the chemical, physical, and mechanical conditions under which it is best to use structural materials, we must confess that there are a large number of dark places which we do not understand in relation to them. We have now as articles of current manufacture ferro-manganese, ferro-phosphorus, and ferro-silicon. A few years ago little or nothing was known of such materials, yet it is understood definitely to-day that with the use of these materials we are able to produce metals of a quality, which without them a few years ago would have been altogether impossible. Nothing is more remarkable than the fact that within the last two or three years we have been able to use, in the manufacture of iron, phosphorus as a fuel, and the complaint is that many of the irons do not contain phosphorus enough to make it possible to get the phosphorus which the raw materials actually contain out of the manufactured product. The government, itself, for its own preservation, is interested directly in this matter. In the year 1868 a commission, of which I was fortunate enough to be a member, was appointed to examine the irons used in the forts of the United States, especially at Fortress Monroe and Fort Delaware. The results of the investigation on the ground, from the effects of 13-inch shot fired at point-blank range, were such as to convince every member of that commission that the iron was bad, and that the conditions of the contract had not been fulfilled. It was, in the first place, in the highest degree not homogeneous, defects of welding, six inches square, occurring in every direction in the plates. The result of the impact of the ball was the giving way of the plates behind in such quantities, and in such small pieces, that a mouse could scarcely have lived inside the fort. The metal was so very brittle that it was supposed to be high in phosphorus. A detail of these experiments has never been published, but the results of the investigation of the materials used, which was continued for more than a year, showed that welded plates never were homogeneous, that the iron was not in the least cold short, and was far beyond the contract-

strength, but we were not given the means to study the results of the fatigue produced by the impact of 17,000,000 foot-pounds.

Of the effects of varying proportions of phosphorus in iron, how little do we know, even though individuals have been studying it more or less for over a hundred years. I give below the partial examination of commercial products made by Prof. Akerman, of Sweden, which are valuable to-day, which five years ago would have been worthless for any purpose.

	No. 1.	No. 2.	No. 3.	No. 4.
Phosphorus, ...	4.70	7.42	10.37	15.
Sulphur, ...	0.04	0.05		
Silicon, ...	0.41	0.88	trace	
Carbon, ...	3.03	2.15		
Manganese, ...	0.18	0.25	0.11	

No. 1 looks like spiegeleisen, but is not so hard. No. 2 has a granular fracture, like ferro-manganese, is tough, but not quite so tough as white, granular charcoal pig, with three per cent. carbon free from phosphorus. No. 3 is granular, like ferro-manganese, but it is so soft and brittle that it can easily be pulverized. No. 4 looks like ferro-manganese, but is so soft that it can be easily cut with a knife. These are valuable products of manufacture made on a large scale for commercial use. Who could have predicted their use or their properties, especially of those high in phosphorus? It has been known in the various mints of the world, that the parting-pots formerly made exclusively of platinum at an enormous cost, can be advantageously replaced by iron containing a certain percentage of either phosphorus or silicon, which will resist the action of acids even better than the more expensive metal. If some means of casting ferro-silicon containing from ten to fifteen per cent. of silicon could be found, it would be an invaluable knowledge, for Dr. J. Lawrence Smith in his investigations on this metal, found that it was not soluble by aqua regia.

It was formerly supposed by all the iron manufacturers that when phosphorus was present in irons it was necessary to put in sulphur in order to neutralize it, and it was a rude shock when it was discovered that irons containing sulphur and phosphorus, were both "cold short" and "red short," but red and cold short only in the proportion of the sulphur and phos-

phorus that they contain Most of these discoveries were made either by the encouragement of the governments of the countries of the Old World, or by men educated as specialists at the expense of their governments. Why should not ours help us to become fully acquainted with our own manufactures?

There is no doubt that many of the imperfections which have produced disaster in the use of structural irons have been owing to the use of bad testing machines, and not only to this but to bad theories in the use of the good testing machines that we have. The habit of testing irons and steels on diminished areas, and then calculating that the larger section was stronger in direct proportion to the increase of area, was one of the most vicious methods that has ever been introduced into mechanical engineering. We know now from the experiments made with the United States testing machine that this is not true. We might, however, have known it years ago, and we probably should have known it had there been a distinct board to make examinations as we now propose. Nothing is more remarkable than the fact announced as the result of a series of careful tests at the Washington meeting of the Mining Engineers, in February of this year, that irons, which by contract would have been rejected if they had been tested upon small machines, were found to be entirely within the contract specifications of strength, when the work was done on the machine at Watertown, and that the contrary was also true in some cases. There is no doubt that many of the failures have been owing to defective testing. Not only are the machines themselves imperfect, but the manner of testing has in a great many instances been defective, for it has been found that the small amount of rest which an iron gets when it is allowed a few seconds of repose in the testing machine, and a new force then applied is sufficient to make the metal appear to have a much greater strength than it really has.

The law of refreshment of metals needs a large amount of careful study, for if irons may be almost instantaneously refreshed and fatigued it is quite as likely that they follow a law, which may, when its details have been ascertained, be capable of indefinite application. It is quite possible too that irons which have been really fatigued may stand for a short time and then give way, which fatigue, if it had been known

beforehand, might possibly have prevented a loss of life. We do not know, and have as yet no means of knowing, whether metals are fatigued or not at the time that they are used, but it is certain that metals which are fatigued may become refreshed, as was notably the case in some of the cannon produced in the Fort Pitt Foundry, which were condemned, but after a period of rest were found to be more than strong enough to pass inspection. We know so little about the results of impact and vibration on metals that these need very careful examination. The study of such obscure phenomena as these, which must first be produced on a large scale and then carefully investigated, can only be done by a board who shall have time and money enough to examine the phenomena in detail. If the United States Government had put in each department men of the same professional ability as have examined the properties of cast-iron for the single use of ordnance, in charge of the investigation of materials used in construction, and had been as liberal in time and in appropriations, engineers would not have been obliged to confess their ignorance, and many a disaster that has brought great distress on corporations and individuals would have been averted, and the Government would have saved more money than they spent.

It is an undoubted fact that a large part of our errors in construction are owing to the fact that the mechanical methods of ascertaining the qualities of the irons were not only in themselves defective, but that the machines were defective, so that as between two machines the results are not and cannot be comparable. In many cases, as has been elsewhere said, the factors of safety which we use are the exponents of ignorance, from the fact that the laws deduced from one set of materials are transferred to another, to which they are not applicable.

Many of our structures are undoubtedly too heavy, and are fatigued by their own weight, and would be stronger if a large amount of the material were removed from them. If we could save three per cent. of the weight of the structures, and still have them strong enough to do the work which they are called upon to do, we should save 6 00 tons of rolled iron, or 21,000 tons of the total amount of iron, steel, and cast-iron produced. It is more than probable that the saving would be much larger

than this, and yet this of itself would many times repay the expense of a commission.

We are using steam boilers, and yet we do not know much about the metal which is essential for their construction. A few corporations have ascertained that there are many points of weakness in the irons usually used for boiler plates, which can easily be avoided, and yet I believe that until within a comparatively short time, it was not possible for the boiler makers to make specifications which would be sufficiently specific to cause an iron to be made which should be light and at the same time perfectly safe.

It is impossible to state how many defects arise from a want of proper chemical knowledge, and yet it is upon this side of the question that almost all the investigations of metals have taken place. Many manufacturers have been in the habit of thinking that what it is most necessary to avoid is having material that is "cold short," while materials of a different character might easily be worked with the greatest possible advantage. Yet it has for a long time been known that red shortness was often a question of temperature, and that a metal might weld above or below the temperature at which it was red short, and give an iron which in appearance seems thoroughly welded. But it is quite impossible even in pieces of really good quality and of moderate size to have a perfectly even weld. Many defects of welding in red short irons are doubtless due to the unequal distribution of heat, and this opens the whole question of welding, which is a source of constant anxiety and perplexity. It is, of course, best in all cases to avoid welding when that is possible, but when it is with our present knowledge not possible to avoid it, there is always a certain degree of uncertainty about any weld not actually made by fusion. Several means of detecting imperfect welds have been devised, but they are more or less impracticable. The method of detecting a weld that is imperfect beneath the surface is yet to be devised and would be a great boon. But why should we use interpenetration welds at all? I believe the day will come, and shortly too, when the defects of such welding can be made as evident to the public, as they were to the United States Commission, who examined the irons used in the armament of Fortress Monroe and Fort Delaware, in 1868, and that they will demand that severe penalties shall be

inflicted on the manufacturer who is known to use any of the old methods of interpenetration welding.

Iron and steel are, however, not the only materials used in construction. Stones, bricks, mortars, cements have been examined to some extent. We know a great deal about these materials as they are used in foreign countries, and this knowledge we apply to these materials as made and used in our own country with a moderate degree of certainty that the laws found to be true in one place will be true of the same material from a different locality; but as our climatic and commercial conditions are so different from those of Europe, we ought to have a knowledge of our own materials, and more especially of the methods of making artificial substances to be used in those districts where stones and cements must be manufactured. The whole question of refractory materials, upon which the safety of so much of our invested capital depends, is almost a virgin field. In some industries we are spending per ton of metal produced, five times the amount found to be necessary elsewhere. If some of the modern iron and steel industries are ever to find a home in this country, many thousands of dollars will have to be spent in investigating this single question. We are now waiting for the results of experiments made abroad, or are using foreign materials imported at great cost, when we should be using our own.

Our knowledge of woods is extremely limited. The experiments that have been made upon them were made mostly in Europe under conditions which do not exist in this country, and so defective is our knowledge that the insurance companies have been obliged to have investigations made upon this subject for the purpose of ascertaining how the material may safely be used in the buildings they insure and be subject to the least fire risk. It seems to be apparent, from a slight study that I have made upon the subject, that as wood becomes scarcer we must have an investigation to know how it can be used economically. It is well known in Europe that woods cut in certain ways will warp, and they also know perfectly well how to prevent this warping by cutting up the log so as to make four sticks of timber from the same tree, and then cutting each stick parallel to the first cut that takes off the bark. By the ordinary method of cutting the tree either into squares or planks parallel to a given direction it is im-

possible to prevent warping. It is also known that the season of the year at which the wood is cut will not only affect its durability, but also its power to sustain a load, and that the season cracks produced by careless piling will also affect its strength. It seems to be quite possible, from a casual investigation of the subject, to construct wooden trusses and bridges which would be stronger with less weight in them than those now used, but in order to ascertain exactly what the best form is, careful investigations similar to those reported, some years ago, to the German Government should be made. The work must be done by a commission, who should feel at liberty to take the time and incur expense necessary to work up the subject.

These—wood and iron, artificial and natural stones, mortars and cements—are the materials most commonly used in construction. But there are other metals and alloys which are used in great quantity, about which we know but little. This is especially true of the copper alloys and of copper itself. Until the publication of the very able report on the copper-tin alloys by Professor R. H. Thurston, very little was known of these alloys.

I have had occasion since 1876 to make many researches, not only on copper, but upon its alloys with zinc, and I find that the material which is called copper and used as copper in the market, is of a very variable composition, and is not all equally well suited for either the manufacture of alloys or for its direct use as copper. The United States produced during the year 1880, 56,899,842 pounds of copper. Of this amount 56,655,140 pounds came from Lake Superior. The value of this product, at an average of 18½ cents per pound, is $10,526,-470.77. The total capital involved in producing this amount was $35,552,401, or $0.625 of capital invested to produce a pound of copper. In 1881 the production was 71,300,000 pounds. Of this amount the Lake Superior district produced 50,000,000 pounds; Arizona, 8,000 pounds; the other States and Territories, 13,000,000 pounds. The total amount sent abroad was 7,000,000 pounds, leaving 64,300,000 pounds consumed at home. One of the largest manufacturers in the United States estimates that of this amount 61,000,000 pounds were used in the manufacture of brass and other copper alloys.

It became necessary for me some time ago to make an investigation on some of these alloys for the cartridge companies, and after making fifty or sixty analyses and investigations of alloys in every condition, I found that it was quite possible to take metal from the same batch, which had been manufactured from the same ores in apparently the same way and put through the various machines under the same conditions, each batch of metal being apparently alike and perfectly homogeneous, and yet one cartridge manufactured from this metal would stand firing one hundred and fifty times, while another, taken from its side, would be useless after the first firing. There was no chemical difference in this material which would justify any such difference in strength. On a careful examination I found the physical conditions not only of the alloy, but of the metals in the alloy entirely different. In some cases when the alloy appeared to be perfectly good at the time it was manufactured and stood all the tests of inspection, if it was allowed to remain a short time at rest it became so brittle as to be perfectly useless. I also found that metal which stood all the tests at first, and was manufactured in large quantities, after months of rest became so brittle that it would tear like paper. After several months spent in the examination of these specimens my attention was called to the general manufacture of punched and stamped brass in the State of Connecticut and I saw tons of refuse material, which had to go back to the melting-pot, not because the metal itself was not good, but because it had, like the cartridge metal, become fatigued in the course of manufacture. Making a careful study of the fatigues in both cases I found that they belonged to exactly the same phenomena. It was possible so to fatigue the alloy, that an unequal cold flow of the two metals took place; I have seen tons of metal in which the zinc had actually started to separate from the alloy, and this was cause of the rottenness. It is quite possible to prevent this in the manufacture, but not to cure it after it is done. The Government is equally with the private citizen interested in all these brass alloys, and an investigation which should arrive at some economical result would be of prime importance to them. As the result of these investigations, made for two different companies, I was obliged to recommend the changing of their entire plant at a very great cost. Such expenditures on

plants, which are new, are a great discouragement to the manufacturer. It means not only the loss of the capital already invested in the works, but the loss of output while the new ones are being built. The Government uses such a large amount of this very material, that they have a real interest in making the investigation, not only in their own pecuniary interest as manufacturers, but also to prevent the loss of wealth to the nation, by improper expenditures.

I was told recently, by a large manufacturer in the State of Connecticut, that it was not an uncommon thing for him to manufacture five tons of brass and put the whole of this material through a single machine for making a single part of a kerosene oil burner, and another five tons for another part, the number of parts in the burner sometimes being as high as eight or nine. Any manufacturer, or any other person who would stand by the refuse-heap of any one of these lamp-burner manufactories would see in the tons of waste material, every ounce of which might have been worked up to a profit, a source not only of private loss, but also of public misfortune, as every ounce of waste material must of necessity increase the cost of the manufacturer's article. In some cases the loss is considered as inevitable, in others investigations, often repeated and never more than partially successful, are made at many times the expense necessary for a thorough investigation. But, gentlemen, private individuals should not be expected to make these investigations. If one hundred manufacturers make the same investigations, one hundred times the amount necessary to make the investigation is expended, the country is thus the loser of ninety-nine times the amount of money necessary to do the work, which is not only a loss of wealth, but a loss of revenue from the money that might have been profitably expended in other directions. What is true of these alloys is true of all metals to a more or less great extent. The law of fatigue and refreshment is so obscure that no one but a commission, with time, money, and material at its command, can thoroughly investigate it, although it may be learned by the individual efforts of those who are willing to make these experiments 200 years hence; time under such conditions is such a factor in the question that the world of our day and of many generations which follow us may never know what these laws are. The same results could be reached by a commission

probably in a few months' experiments, and be published by them at once for our benefit, and thus anticipate an enormous expenditure both of time and capital. The whole world is interested in knowing what the proper conditions for use are for materials which enter in so large a measure into the safety and comfort of our everyday life.

Another unanswerable reason why the Government should appoint such a commission as we propose, is, that such a waste is not only a loss of time, labor, and capital, but it is a real discouragement to the investment of capital in such manufacture, and besides it increases the cost of the production of material and therefore really diminishes the wealth of the country. It is easy to say that private manufacturers have it for their interest to undertake such examinations as this, and this is true. My own professional experience is full of just such investigations, but when they are made they are the private property of those who had them made and are kept secret, in the interests of the persons who had them made, and justly so, and the sum of human knowledge is not increased and the world is no better, but is rather worse off, from having such private investigations as these constantly repeated. No manufacturer who has ever made them would communicate the results to his competitors if the result had been one which he could translate into a commercial benefit to himself, and no one would be justified in asking him to do so.

The United States is the largest single consumer of constructive materials; next come the railways, and while the United States, though most directly interested, is doing little or nothing, only a single railway corporation is making investigations for itself, which makes it what it is now, probably the best managed and the greatest railway that the world knows. What should be done is to build structures and test *them*. Let us put up a bridge, a truss, a roof and columns, put in, load, and break them, reinforce, reload, and break again. Under such conditions, I believe that but few of our present forms and shapes would continue in use, and that we should demand different qualities of metal, and be able to tell the manufacturer how to make them to his own and the consumer's advantage. We shall then come nearer to doing what the Creator, the GREAT ENGINEER, has done with all His creations. If, as the results of the work of such a commission, we could increase

the profitable use or cut down the weight of constructive materials 3 per cent., the United States would gain every year over $100,000 in each of its navy yards.

The old commission have settled once for all that the testing on a diminished area gave false results. What we know of testing on full sizes is the work of this commission, and that is extremely meagre. It is one thing to know what the individual member of a composite structure will resist, and quite another thing to know what it will do in combination with others. It is one thing to know what strain these composite members of a bridge will bear separately when new, and when fatigued what they will support under loads of certain kinds; it is quite another thing to know how the strain will act on all the composite parts put together. What we know about this subject has been learned mainly from disaster, and these disasters do not teach us what a test commission would, for the reason that disaster is always unforeseen, and there is no time to study anything but after effects, at a time when every one is horrified by loss of life, or depressed by injury to property. The discussion of how such an accident might have been prevented becomes profitable for the future, when (and in many cases this is not possible), all the facts of the case can be ascertained. It is but meagre comfort to those who feel the ruin to know that the disaster would have been prevented if certain laws of strain had been previously studied, and that their ruin was the only stimulus which could cause the investigation to be made. Science and the progress of human arts should never be advanced by disaster. We should examine all constructive material beforehand, studying each part, building and breaking the whole, and then reinforcing the weak places, building up and breaking again, until we *know*, with absolute certainty, that the duration of all those structures, upon whose safety human life and property depend, will be assured beyond peradventure. There is still another side which needs to be considered. If a building or a machine is constructed properly it will be capable of supporting or producing one hundred per cent. of work. If not, the product will be diminished more or less. Recent investigations have shown that from the imperfect construction of masonry, beams, girders, or machines, the amount may be reduced to fifty per cent., a loss of half. What are the conditions of defect? in how many cases

are the remedies applicable to structures already built? how can they be applied? No manufacturer or corporation can settle such questions. A government only can do it; and who can tell what sources of wealth may spring from such an investigation, properly conducted, in such towns as Lowell and other great manufacturing centres?

As engineers we are perfectly willing to confess our ignorance. We do not know, we cannot know, and we never shall know until the Government appoints a commission to do what we ask. When the public can once be made aware that this thing ought to be done, it will not be we who ask Congress to do it, but it will be they who *demand* it to be done.

I have thus wished to call attention to a few of these facts, —to the fact that modern metallurgy has developed processes which give physical and mechanical characteristics to the metals now being used entirely different from those which pertained to those metals at the time the factors of safety were determined; that letting alone factors, we must look for new forms of metal; that we must use the same metal to produce an entirely different result, and that we must not only look for new forms, but for new chemical combinations.

It was my privilege some years ago to announce at the Montreal meeting of the Institute of Mining Engineers a law which I believed to be entirely new—a law of fatigue and refreshment of metals. This law has assumed proportions which appear to be of much greater moment than I had any idea of at that time, for it has turned out since I have been investigating the subject of fatigue and refreshment that other engineers have found similar phenomena, and that there are, very often, kinds of fatigue of which we know but very little. I instanced, in the paper which I read at Montreal, the fact that some metals become fatigued by apparent rest, as in the case of cartridge metal, which has already been cited. This was fatigue that actually existed in the metal, but which was developed afterwards by the fact that no work was done in it. The most extraordinary instance of fatigue, however, which has come to the knowledge of engineers is in the fatigue which occurred in Fribourg on some tin rings which were exposed to constant vibration in the steeple of an old church for nearly two hundred years. These rings had been left there by accident, and had been subjected to a very slight vibration for

that length of time. When an attempt was made to remove them it was found that they were in the condition of an impalpable powder. It was supposed that they had been converted into oxide of tin, and that for some reason, either chemical or physical, the rings had oxidized thoroughly. But finally the rings were raised without disturbing the powder, and by the application of heat they were restored to the metallic form, just as strong as before. The restoration from fatigue, which occurs from rest, is better illustrated by a fact known to some of the cannon manufacturers and brought to my attention by Mr. Metcalf. It is a law of the government that any cannon which is condemned shall be immediately broken up. One of the cannon, condemned by the government officers, was not broken up. It got covered up and instead of being broken up, lay for fifteen years in the sand, and was finally dug up and tested. It was found that not only was this cannon not fatigued, but that it bore an amount of fatigue which could not be borne by any ordinary cannon. The case of fatigue where the metal is fatigued but does not show it, I have already cited to you in the case of cartridge metal, of which perhaps more than half a million cartridges were destroyed in this way in the manufactory of a single company in Connecticut.

Now, gentlemen, such things as these require to be examined. A great many of us engineers are under the impression that a metal can be used under certain conditions, and that it does not make much difference under what conditions it is used, provided it is safe for the time being. I think an investigation will prove, if made, that we are very much at sea with regard to such matters; that we need to investigate in some of these directions which I have pointed out, and in other directions as well, of which we can only know the details after this commission shall have been at work for some time, and which are undoubtedly equally important, and that a commission should be appointed by the United States, under the same conditions as the old one, and that this commission should sit as long as there is anything to be discussed in constructive material. Metals are not the only things. We ought to discuss everything relating to stone and bricks, everything relating to mortar, everything relating to wood,—in fact, everything that we use in any way whatever, in the construction of

machines, in structures that we use above ground or below ground, or that we use on the sea, ought to be examined. I had a discussion, some time ago, with a very large firm of boiler-makers, in this city, who told me that when they began to draw specifications for the making of boilers, they found that there were no investigations that were satisfactory, that they could rely upon, for the use of boilers, even for ordinary pressures, and that they were obliged to go to the iron manufacturers, and demand certain things of them, which the iron manufacturers told them were impossible, but which seemed to them to be absolutely necessary, in order to make a boiler with ordinary safety. We think that there ought to be a commission for the examination of these, and of other things of the same nature.

The work which such a board would have to do might last almost indefinitely. The work of the old board is in the minds of most persons confined to the work of a testing-machine at Watertown. What we need, however, is not this machine alone; we want that, but we want many other machines also, which should be devised for the purpose of doing different kinds of work under different circumstances, and we wish to have machines built for the purpose of making special tests. It is not only the structures that we are in the habit of using, but other combinations that required to be tested; not only the materials in the form in which they are now used, but in all other possible forms; and I am quite certain, and I think every engineer will agree with me, that before such a commission has finished its work, it will be found that the economy in weight, resulting from ascertaining the proper forms for greater strength with the same weight, would more than pay in a very short time for the whole investigation.

What is quite as necessary also, as getting at the facts, is the publication of these facts. No engineer working for his own professional reputation could be made to publish his failures, yet the failures are often more instructive than the successes, while a commission working for the purpose of producing failures would gladly publish everything, both failures and successes. Such a commission should publish everything that they do, invite comment from engineers at home and abroad, test all the theories which are advanced by engineers of sufficient reputation to entitle them to a hearing, and then publish

these results again inviting further comment, and so on. The commission then, instead of being composed of seven members, as proposed by the bill now before Congress, will be composed of all the engineers in the world who would be willing to give a sufficient amount of time and thought and take enough interest to discuss the facts; and every engineer would consider it an honor to have made a single suggestion to this commission which would help them to produce any new results.

Such a commission should in my opinion serve without pay. They should assemble at stated periods, and should direct the experiments, while those who are employed to do the actual work should be paid a reasonable salary. Any engineer of reputation and of moderate means could well afford, for the honor that he would obtain from it, to *give* the necessary time and thought involved in this work. The members of the board, however, should not be expected to do clerical work of any kind. Plenty of men could be found to do it at a small cost, certainly just as well and probably better than the members of the commission, who would then have all their time and thoughts devoted entirely, not to clerical work, but to the labors of investigation which would devolve on them. After discussing this matter at great length in Washington, the committee who had charge of the bill decided that this clerical work could best be done under the supervision of the Department of the Interior, and if they were left at liberty, as the bill anticipates, to form their own organization and do their work in their own way, without political interference, I have no doubt that the results after a very few years of the work of such a commission would add largely to the reputation of the citizens of the United States for far-sightedness and enterprise, and contribute so much to our knowledge of the real properties of constructive materials as would not only decrease the cost of living, but add so much to real and substantial comfort as to increase the average of human happiness and life.

I shall not take up the time of the society any longer. I trust that some of the other gentlemen who are to speak, will make suggestions in regard to what ought to be done and will call out facts which do not occur to us who are on the committee. The committee have decided that it is in the first place desirable that this work should be done, and in the second place that it is desirable to memorialize Congress, and

a memorial has been drawn up for circulation among those interested directly or indirectly in this subject; and then that the committee should act with a committee of the Society of Civil Engineers, and of the Institute of Mining Engineers, to endeavor to make Congress do what we think ought to be done. If the world at large knew, or if the people who are using our machines and bridges and constructive materials, knew what the actual facts were, and what the dark places are in all of these different constructive materials, we should not be obliged to memorialize Congress at all. The people would go to Congress and demand that the thing should be done, and engineers would not be allowed to do it, they would be forced to do it.

I hope that all the members of the society who are interested in this matter of tests, will take pains to see that the memorial, which will be sent to them in the course of a few days, will be signed, and signed extensively, not only by persons who use metals, but by manufacturers of every kind, because I think it will be shown that every manufacturer, if he is under a roof, has a direct interest in having all the factors of safety and all the other properties of metals re-examined and redetermined.

I have a copy of the memorial here, but I did not bring with me a copy of the bill "for testing metals and constructive materials," prepared by the joint committee. I may state that the Society of Civil Engineers appointed a committee in June last. This committee sat until January and reported to the society, and then the society decided that through its board of direction the society itself should take up the matter. They prepared a memorial to Congress, and came to Washington represented by the president and secretary. The Society of Mining Engineers was then in session in Washington, and a committee was formed, composed of eight members, who were members of the Mechanical, Mining, and Civil Engineers societies, to draw the bill now before Congress. The proceedings of the meeting in Washington, which was held for that purpose, are printed and can be obtained on application to the Secretary of the Society of Civil Engineers, or the Secretary of the Society of Mining Engineers. The action taken in Congress was to refer this to a committee, and it is now in the hands of Mr. Campbell, who is chairman of the House Committee on Manufactures. This bill has been read twice and

is before the committee. It was hoped that the bill could be passed at this session of Congress, but I think that has become hopeless, owing to the fact that there has been opposition, both latent and fully developed, to any commission whatever being appointed, under any circumstances, and the committee now call for information from engineers and others directly interested in having this bill passed. This is the condition in which the matter stands to-day, but if the bill is not passed during this session, there is very little doubt that it will be passed at the next session, if all the engineers join in doing what I think they will do when they become acquainted with the facts. And I will say here that the Civil Engineers, after talking the subject over with prominent officers of the army and some of the navy, and some of the most prominent legislators in Washington, decided that it was best to have a civil commission entirely, and not a mixed commission, to perform this duty, that at least one person on the commission should be a manufacturer of metals, that there should be at least one who was an engineer skilled in construction, and that there should be investigators, etc., and that all those who were members of the commission should receive nothing but mileage. They should have the power, however, to select and employ experts; and that the whole of the accounts of the board should be audited in the Interior Department, and the board left to do the work for which it was appointed, solely and wholly; that the work of the board should be published monthly, whenever it had any results, and results only should be given at first; and at the end of the year, after the criticism of the engineers of all the world had been invited to these results, the board could then undertake to make a report on the subject of their tests. That the board should be appointed in such a way that they should give their time and thought, but do no handwork and spend no money of their own; that the sessions of the board should be only for the purpose of directing those who are actually doing the work, and who were salaried, what to do and how to do it, and for discussing the results.

The memorial prepared by the committee, read as follows:

MEMORIAL

TO THE HONORABLE, THE SENATE AND HOUSE OF REPRESENTATIVES OF THE UNITED STATES, IN CONGRESS ASSEMBLED:

"THE undersigned, members of the AMERICAN SOCIETY OF MECHANICAL ENGINEERS, and other citizens, respectfully represent, that under the authority given by an Act of Congress, approved March 3d, 1875, the President of the United States appointed a Board, to test Iron, Steel, and other metals. That this Board made a large number of chemical, physical, and mechanical experiments, and built a testing-machine which has no equal; but, that its term of office expired, by limitation of law, June 30, 1879.

"That the work of this Board was of the greatest value to all the engineering and constructive sciences, but that its term of office was so very short, that a large amount of work of vital importance both to the United States Government and to private citizens yet remains to be done.

"That it is of the greatest importance both to the consumers of all materials used in construction, as well as for the public health and safety, that these materials should be used to give the greatest amount of strength consistent with the most economical use of the metals, for which purpose it is necessary that all the materials used in construction should be tested.

"That the tests heretofore made on these materials have been for the most part made on specimens of diminished area, and under such conditions that the tests are not comparable.

"That very many of the tests, which were made the basis of the formulæ upon which engineers rely for their calculations, have been made on material manufactured under different conditions from those which exist in this country, and that this fact, together with the above-mentioned of the tests having been made on specimens of diminished area, make their conclusions doubtful.

"That the new metallurgical processes, which have been invented in the past twenty-five years, produce metals of a quality altogether dissimilar to those formerly tested, and that it is most desirable that information should be had relative to qualities of metal and materials used in construction, which were almost unknown when the former tests were made.

"That the tables of factors of safety now in general use, were constructed under conditions which no longer exist, and that it is for the interest of the United States Government—which is the largest consumer of metals and constructive materials in this country—to have these factors redetermined, as the result will undoubtedly be, that a diminished quantity of material will be used in a much safer form.

"That while it is undoubtedly for the interests of corporations and private manufacturers to make these tests, it would be against their interests to publish them when made, and that the constant repetition of the same experiments would consume a large amount of capital, but would add nothing to the general knowledge of these materials, and that the absence of this knowledge has undoubtedly caused not only much destruction of property, but also the loss of many lives.

"That the knowledge which it is desirable to obtain, can best be arrived at by the appointment by the United States Government of a Commission of skilled experts, appointed by the President with the sanction of Congress, with a sufficient amount of funds at their disposal to make experiments on members of composite structures of full size, and on the structures themselves—to determine not only what is the best quality, but also the best form in which to use the materials—whose duty it shall further be, to examine into the laws which apply to the safe use of all kinds of materials, used in constructions, and to deduce from their experiments formulæ and rules for the best and most economical use of all such materials.

"The prayer of your memorialists, therefore, is that your Honorable Body will empower the President of the United States to appoint a Commission from among experts in the manufacture and in the use and the investigation of materials used in construction, whose duty it shall be to plan and execute the needed investigations and tests upon materials used in the manufacture of machines, buildings, bridges, and other constructions, to deduce such rules from them as will lead to the greater safety of the structures, and economy in the use of the materials of which they are made.

"And your memorialists further pray that such appropriations may be made by your Honorable Body as to enable the Commission when appointed, to make the tests and experi-

ments on full-sized parts of structures, as well as on the structures themselves, and also to construct such machines as may be necessary, and also to secure the services of such skilled experts as may be necessary to carry on the experiments.

"And your memorialists will ever pray, etc."

DISCUSSION.

MR. WOODBURY: *Mr. President:* I think we all ought to favor this measure, because the results which will be obtained from the investigations proposed, will apply to the interests of us all, whether we are constructors, or whether we are owners of buildings, of bridges, of structures of any kind. In fact, it pertains to the whole range of the mechanic arts. There is an amount of failure in general construction which never becomes known, because those concerned in it are very careful not to have their methods known; and in most matters of construction we all know that we have nothing but a precedent to rely upon, and that precedent of course becomes faulty when the nature of materials changes. It is an axiom throughout physical science and the mechanic arts that it is bad policy to work from the less to the greater, because the errors are augmented, and in the structure of various materials, the strength of the whole is no multiple of the strength of the part. The tensile strength of a large bar of iron is not a direct multiple of the tensile strength of a smaller section. Even the data which we have for such purposes are largely drawn from foreign experiments with foreign materials; and those experiments which all of us have probably made, have been carried out on a very small scale. Later on we shall perhaps hear something further about this subject when Professor Lanza reads his paper on the resistance of wood columns. Wood columns are generally used in our mills in the East, where they are preferred to iron for many purposes, and yet until these experiments were made, all the formulæ which are given in the engineering books for the strength of wood columns, are based upon the compression of columns of Dantzic oak, a material not known in our markets. The experiments were made a great many years ago. The columns were very small, some two and a half inches in diameter, and were mere models. That is a question with which I have been brought face to face in certain matters, and I do

not know of any data on the strength of wood columns, such as were very readily obtained with this Watertown testing-machine; because the results which this machine furnished applied to the interests of every one. I certainly hope that the influence of this society will result in causing the testing-machine to be put to such uses as will be available to the general public.

MR. OBERLIN SMITH: I am not very familiar with this subject, although I am placed on the committee. I feel that the other gentlemen who have made a study of it can say all that is necessary to be said. I can only add that I for one give my most earnest support to this whole measure. I think it is of vast importance. I should like to see the government spend a round million every year on just such work. It would return a hundred-fold. The trouble with people not engineers is that they are indifferent. They do not realize the importance of it. They do not know what this kind of work is. They do not know what the results of it are when it is done. They feel very sympathetic when a mill falls, as one did some years ago at Lawrence, on account of a defective column, and hundreds of men and women were burnt to death. There were no means of knowing whether it was strong enough or not. There was the giving way of the bridge at Ashtabula, and I may say that I escaped that accident by one train while on my wedding tour, so that it is always brought vividly before my mind whenever I think of it. Then there was the Tay Bridge disaster. When such an accident happens people sympathize with the sufferers, but they do not know enough about our profession, about the laws of physics,—you may say that the public in general haven't enough common sense—to understand what such accidents mean. The only thing we can do is to keep agitating the matter in every way; to make personal appeals to members of Congress and members of the Committee on Manufactures, who have the thing in charge. We certainly all hope it will be the means of accomplishing good. I hope that all the members of this society and of the sister societies will take the interest they ought to in the matter, and get all the signatures they can, and of the right kind. It was suggested in our committee meeting this morning that it was not of much account to have on that petition the signatures of people entirely unknown and obscure,—some of them with a mark

affixed to their names. It would be very easy to get a hundred thousand of such signatures, but they would not count for much in relation to such a subject. The petition is to be divided into columns for the names and business of the signers, and I don't know but that it would be well to state the title as well, where, for instance, a man is the president of a company. The idea is to carry that petition into Congress signed by as many prominent men as we can get,—men of weight in the community; not only men who are known to the people as manufacturers, but men who can influence Congressmen through their general public position. I do not know that I can add anything to what has already been said on this subject. We are all familiar with the accidents that are constantly happening, and, as Professor Egleston suggests, it is not only the loss and danger that results from the breaking of a machine, but an accident of the kind damages a manufacturer's business, and in extreme cases it might ruin his reputation,—ruin it in a certain line at any rate. I call to mind an incident which happened in a shop, in my presence, which illustrates this point on a small scale. A so-called safety hoist, having differential blocks, broke with a pair of heavy grindstones. It fell down. There were a dozen or so men standing around, some of whom barely escaped being killed. Since then the men hate differential blocks. If that thing had not happened the course of affairs would have been different. Those blocks would still be used in that shop. I hope we shall hear from more of the members on this subject, as it is a very important one.

Mr. Barr: Some four or five years ago, the company of which I was then superintendent contracted for the erection of a large cotton compress. The duty required of this machine was to compress an ordinary 500 pound bale of cotton, which, as delivered by the local ginning establishments in the South, occupied nearly five feet in height. This was to be compressed to 12 or 15 inches in thickness, for reshipment North. A stipulation in the order for this press was that it should be capable of exerting a final pressure of 2000 tons on the bale. Calculations made at the time of construction showed ample power for such pressure, and, the designs having been very carefully prepared, the press was believed to be amply strong for the work. The remarks by Professor Egle-

ston and Mr. Woodbury on the strength of materials bring to my mind just now a failure in that press, which may be of interest to those who have occasion to make large castings which have to endure enormous destructive strains.

This press had two movable cast-iron platens, the upper one (which is the one in which failure occurred) was about 30 inches deep; it was operated by four 6-inch wrought-iron bolts, one at each corner. The threads were cut to the Franklin Institute standard, and were fitted with cast-iron nuts. From each corner of this platen there were diagonal ribs crossing each other in the centre; there were, also, ribs extending around the outside of the platen. Unusual care was exercised in designing this platen, as was also in the foundry, that the casting should be as free from defects as possible. Notwithstanding all the care exercised, this upper platen broke after less than two weeks' use, and under a strain considerably less than the stipulated 2000 tons. The fracture showed a defective casting, and the fault lay wholly in the design; that is to say, in making the two diagonals cross each other in the centre. Nearly every engineering textbook gives the strength of cast-iron. These values are determined usually by testing very small pieces, seldom more than 1 inch square; this is all very well, but it does not go far enough for everyday use in constructive engineering. If we take the values ascribed to these little quarter-inch specimens, or inch specimens, it would be very easy to demonstrate that we never could have applied power enough through those four bolts to break that platen; but it did break. Now with such a testing-machine as this at Watertown,—I have never seen it; I am not sure that I ever read a full description of it,—but it seems to me that if we can test the strength of large castings,—if castings can be specially made in which there will be ties crossing each other, in which there will be heavy ribs and light ribs, ribs of the same thickness and ribs of different thickness,—it seems to me that a few experiments of that kind placed on record will be worth to the engineering community at large and to manufacturers fully a hundred times more than it would ever cost the Government to make them.

Mr. Kent: It may be a matter of interest to the membeıs of this society to know what the members of the Engineers' Society of Western Pennsylvania said on this subject last Tues-

day night. I do not think their action has been communicated officially to the other societies yet. The resolution passed by them on the subject is as follows:

WHEREAS, the American Society of Mechanical Engineers has addressed to Congress a Memorial praying for the appointment of a Commission to test Iron, Steel, and other metals, and for the appropriation of the funds necessary to defray its expenses; and,

WHEREAS, a bill has been introduced in the House of Representatives, numbered House of Representatives 4726, for this purpose, and is now pending before the Committee on Manufactures;

Therefore, be it Resolved, That we concur in the views expressed in said Memorial, that we heartily approve of the aims and purposes of said bill, as of the greatest importance to the public in general, and the industrial and engineering interests of the country in particular;

That we respectfully but earnestly solicit our representatives in Congress for this district to use every effort which will accomplish the speedy enactment of said bill into law;

That the Secretary be instructed to communicate copies of this resolution to Congressmen Erret, Bayne and Shallenberger, and to the Chairman of the House Committee on Manufactures.

It seems to me, Mr. President, that this subject has got beyond the necessity for further discussion in engineering societies. As one of our members has just said, the public are not yet educated in regard to it; but worst of all, Congress is not yet educated on the subject. The position now is the same as where a district wants to send a good member to Congress instead of a poor member. The first thing to be done in such a case is to induce some good men in the district to use their utmost efforts to whip the ring at the primaries. If a large number of good men do not take the matter in hand, there will be no good man sent to Congress from that district. So in regard to this bill. The question is how to get this bill passed through Congress. The time is now one for action, not for argument,—we have all been argued to death on the subject for the last five or ten years. The Engineers Society of Western Pennsylvania passed this resolution unanimously. I have not the least doubt that all the engineering societies in the country will do the same. The bill should be passed. The only question is what is the best way to let members of Congress know that it is for the public good, and that the public demand such action. I leave it to the older members of the profession how to engineer members of Congress. I know nothing about it.

Professor Lanza: I am intensely interested in this discussion, especially as I have been doing some work of the character spoken of quite recently myself. I do not see how I can add anything to what has been said; but there is one point which I should like to emphasize. I refer to the importance of making our experiments under the same conditions, as nearly as possible, as are found in practice. Indeed, in many cases, in the formulæ that we use, the conditions that exist in practice have not been taken into account. It is often impossible to do this absolutely, and it is only by coming as near them as we can, and then forming our judgment upon the parts that we have ascertained, that we can do our best engineering work. As an instance, take the case of columns, which has been referred to. The load in practice is not always directly along the axis of the column, but it is frequently brought alongside, and yet none of our formulæ for columns take account of this fact.

It is recognized by the physicist that the results of experiments can safely be applied only to a small extent beyond the range in which the experiments have been made, and that they will not apply to other conditions than those under which they were made; and it seems to me that the matter of approaching as nearly as possible the conditions of practice is a matter that a commission can carry out more successfully than any private individual.

Another question which they are discussing in Germany, is whether riveted connections are not better than the American style of pin connections. Now a commission can investigate questions of this character. The question of mortising beams in building is another which has received hardly any attention whatever in the way of experiment.

I was very much pleased to hear it mentioned that the commission ought to carry out experiments, not simply with the machine, but with other means; thus, there are, at the Watertown Arsenal, immense piles of cannon-balls, which might well be used for determining the effect of a long-continued load on full-sized structures or parts of structures. I sincerely hope that such a commission may be appointed, for I do not believe that the need in which we stand of the information that will be derived from their investigation can be overestimated.

Professor Thurston: I do not wish to let this matter pass

by without having a word to say in regard to it. It is a matter which has interested me intensely for a long time, and perhaps it would interest the members somewhat if I were to tell them more in detail of the history of the movement, what has been done, what remains to be done, and what it is hoped may be accomplished hereafter. The movement for the creation of such a Board as is now again proposed began years ago, so far as I am aware, in the Society of Civil Engineers. A committee was formed by that society, a number of years ago, to consider this subject and to draw up a series of resolutions that should lead to a discussion of the matter, and finally to the formation of some scheme of testing the materials of construction. The Board of Direction of the Society of Civil Engineers approved the matter fully, and facilitated all the efforts of the committee, and the result, finally, was that Congress was memorialized, in precisely the way we propose to memorialize it again, asking for the formation of such a commission. When these memorials had been circulated, a number of the members of the committee and several members of the society, and others interested in the movement, who were not members of the society, went to Washington and obtained an interview with the proper committee of the House. Several of us represented the case as well as we could, and we were given a reasonable hearing. In fact they gave us much more time than they had proposed to allow us, and listened with a good deal of interest to our representations. And when the gentlemen retired, and the committee were left to their deliberations, they discussed the matter for a short time, and presently one of their members came out and asked if $20,000 would be enough to do the work proposed. He was informed that $20,000 would make a beginning. He went back to the committee, and after a time there was inserted in the appropriation bill a provision for the application of $75,000 to the work. After some vicissitudes, such as always occur in legislation, it finally went through Congress, and a Board was appointed, and the appropriation of $75,000 was placed at its disposal.

But before this time, Colonel Laidley, commanding then and still the Watertown Arsenal, had been desirous of obtaining a good testing-machine for doing ordnance work, and the chief of the Bureau had succeeded in getting an appropriation of $25,000 for the building of a machine, and a contract had been

entered into with Mr. Emery, the inventor of the one finally built, for the construction of such an apparatus. When the Board was formed, that contract had lapsed, or was about to lapse, but immediately on the creation of the Board the plans of the machine were laid before it. They were examined by a sub-committee of the Board and thoroughly approved, and instructions were given to the inventor to prepare a contract. At the same time there appeared before the Board Mr. Charles Emery with a modification, or another form of machine, and it was considered desirable to combine the two forms; not that we doubted the efficiency in any sense, or the accuracy or sensitiveness of Mr. Albert H. Emery's machine, but the Board wanted also to have on hand something that it could use either in case of the disablement of the Albert H. Emery portion, or in case it should prove that it might take longer to construct the machine than the contract term. The contract was made and was to be fulfilled in four months. It was done in four years. In the meantime the Board was expecting this machine to be completed, and ready for work; at almost any time from month to month, it hoped to hear that it was so far along that it could be used. But the construction was retarded, and the Board never did succeed in using it at all. As soon as it became evident, in fact before it became certain, that we were likely to be detained, a plan of investigation was laid down which was very complete. The members consulted directly and indirectly with all those people, throughout the country, who were likely to have an interest in the matter, as to the best method of doing the work, and we received communications from leading engineers, from departments of the Government, and from other quarters, that led to the planning of a system of investigation that was thought, at the time, to be as reasonable as complete.

The extent of the field to be covered by this investigation may be judged by the details which are given as to the several minor investigations. One matter,—I have them in alphabetical order,—that seemed to be important, was the consideration of the subject of the abrasion and wear of metals in actual use. One section of the Board was instructed to examine and report upon the abrasion and wear of railway wheels, axles, rails, and other materials, under the conditions of actual use. Another subject, brought up by the Army and

Navy members of the Board, was the study of the kinds of metal best adapted for the construction of armor-plate, and the conditions under which armor-plate could be most thoroughly relied upon to resist the impact of shot. That investigation was confided to members of the Board under the chairmanship of General Gilmore. On that investigation some little work was done as on the preceding, but not enough to justify a report from the committee, and nothing has appeared, or will appear, in the Report of the Board in relation to such matters. They represent incomplete work.

A Committee on Chemical Research was instructed "to plan and conduct investigations of the mutual relations of the chemical and mechanical properties of metals." Up to that time, so far as I am aware, no tests of metals were ever made in which the metal tested had been identified by its own peculiar properties. It had been stated, by persons who had tested metals before, that in breaking down a bar or girder, made by a certain manufacturer, certain densities were found and certain resistances to fracture were measured, but nothing was said as to the character of the metal. We simply had to infer that, if it were made by a certain manufacturer, it was of excellent quality, or, if made by somebody else, it was of poor quality. No examination was made of its physical structure. And this Committee on Chemical Research was expected to examine and report on the mutual relations of the chemical and mechanical properties of metals. That is, to test pieces of metal; determine what were their mechanical properties; what was their resistance to strains; what would be the amount of stretch under certain conditions; under what conditions they passed the elastic limit; where that limit was; what resistance might be met with in case they were attacked by impact. And having done that, a chemical analysis was to be made, and a physical examination of the metal, so that when the work was done, we should say, not that a metal, made by a certain company, exhibited these properties, but that a metal having 98 per cent. of iron, and a fraction of 1 per cent. of carbon, and the balance in other impurities, exhibited a certain density; had a certain amount of stretch, and certain other properties and qualifications that were exactly specified. When an investigation is made in that way, of course you know precisely what to infer, and up to the time when that committee com-

menced its work, no such thing had ever been done, so far as I know. It was the rule from the beginning never to say that a piece of metal, made by the Phœnix Company, or some other company, exhibited a certain density; but to say that metal having a certain composition determined by careful chemical analysis, and having a certain structure, gave certain results. And when the results obtained in all these directions of research came to be placed upon record, it was a record for all time. That this was one of the investigations planned and entered upon, and the results, so far as any were accomplished, will be found in the second volume of the Report of the Board, which is now in press. I have already sent to the printer the complete volume made up with plates inserted with directions for the binder. So that it will be ready just as soon as the printer and binder can get through with work that is pushing them during the session of Congress. I doubt if it will be completed until after Congress adjourns. A new edition is being issued of the first volume.

Another investigation, which was planned, and to a certain extent carried out, was upon chains and wire ropes. The committee was instructed to determine the character of iron best adapted for chain cable, the best form and proportions of link, and the qualities of metal used in the manufacture of iron and steel wire rope. That committee took up its work, and investigated one section of it with some degree of thoroughness. The manufacture of chain cables was studied in all its details, from the point at which the cast iron entered the puddling furnace to the point at which it became a finished chain, and the result of that investigation was to discover some very important matters bearing upon the value of chain cables; their strength, their density, and their liability to break under the surging of a ship at sea. And it was found incidentally that the density of a piece was affected very greatly, not simply by its strength, but by the amount of work done upon it in the rolling-mill; and to my mind the fact brought out by that committee, that iron can be made of as high tenacity in large sections as in small, within certain limits, was one of the most important matters brought out by the board. It was found that one-inch rod could be got having a certain strength, and from the same metal bars of two inches diameter could be made having pretty nearly equal

tenacity. Previously iron had been rolled in the mills from piles of certain convenient sizes. Small sizes of merchant bar are now rolled from piles relatively larger than the larger sizes. Consequently there is more work done, and higher tenacity, greater uniformity, and better quality generally are obtained. This investigation showed that these same qualities could be obtained in the same iron in larger sections by taking the precaution to do the same amount of work there.

That investigation was published in full in the first volume. It will appear in the edition about to be published, revised, and somewhat extended, supplemented by a report on the later work of the Board, and with a complete revision of the earlier results.

Another matter which it was proposed to investigate was the corrosion of metals. The gentlemen to whom it was intrusted were instructed to investigate the subject under the conditions of actual use; how exposure to moist or dry air would affect the corrosion of metals; how the presence of other metals in contact with them would affect the rapidity of the corrosion of such metals. That investigation was simply planned, but never carried out. The Board went out of existence before it made fairly a beginning. The committee did as other committees had done; it sent out circulars to everybody to whom it thought the matter would be of interest, or from whom it thought it could get information, and to engineering societies at home and abroad. Wherever information could probably be obtained relating to such matters it was sought, and it was supposed that in the course of time a large accumulation of facts would be gathered from other sources, which would be a valuable part of the report of that section of the Board.

Another investigation was to determine the effects of variations of temperature upon the strength and other qualities of iron, steel, and other metals. One of the best series of experiments ever made on this subject was made by a committee of the Franklin Institute, of which we are the guests, some forty-five years ago, and you will find the report of that committee in the Journal of the Franklin Institute for about 1836 or 1837; and since that time, so far as I know, nothing like an extensive work has been done. This Board proposed to take up that matter and make that investigation a very complete one, and in the meantime to seek information from other bodies and

from other individuals, and from various sources wherever it could be found, and so compile something that should be really valuable. That is an investigation that remains yet to be carried out.

Another committee was instructed to arrange and conduct experiments to determine the laws of resistance of beams, girders, and columns to change of form and to fracture. That committee got about its work rather late. Other work stood in the way; and about the time the Board saw its last days approaching that committee did get some work done, and you will find the results, valuable so far as they go, published in the second volume of the Report of the Board. That committee should have had at least a year to pursue that investigation. In connection with its own investigations, it would have studied up the work done at home and abroad. A great deal of work has been done on the subject. You will find in the transactions and records of foreign societies a vast amount of extremely valuable matter on this subject. This is a matter that will require the study and work of the new Board for probably several years. It is a matter of such great importance, of such supreme interest, that as long as engineers continue to work with these materials of construction, they will be compelled to revise and to continue their experiments.

An investigation was to be made of the properties of malleable iron. The committee was instructed to report upon the mechanical and physical properties of wrought iron as a material of construction, not in any special form, but the material itself. It was proposed to take all the kinds of wrought iron in our own and foreign markets, and find out what exactly were the properties, and how, with variations of composition, those properties themselves varied. There is an immense field of investigation there, simple as the matter seems. The gradation that is now going on from wrought iron into steel, and through the mild steels into tool steels, is one that is like the fading of light into dark; and this investigation would have gone on and dovetailed into the investigations on steel made by other sections of the Board. That special investigation had not been made. Plans were made, very completely I presume, in this case, and the plan of campaign having been formed, it would have been a much less difficult matter to have gone on from that point, and to have made the investigation and com-

pleted it, than it will be now, when we must lose all this preliminary work and begin right at the foundation.

Another investigation was of exactly the same character in regard to cast iron, the mechanical and physical properties of cast iron as a structural material. You will see, as I go on, how all these matters dovetail into each other and finally form one complete whole. I do not know of any department of the study of engineering materials that is not brought in here.

Another study was that of metallic alloys. The instructions to the committee were, " to assume charge of a series of experiments on the characteristics of alloys, and an investigation of the laws of combination." That investigation was carried out more completely and more thoroughly, and so far as the first investigation was proposed to be carried out, more satisfactorily than either of the others. The plan of operation was very complete, and the facilities for carrying it out were given by the Board. The means were at our disposal. We required small testing-machines, not large ones; and the consequence was, we were able to put two or three men at work, men who took an interest in the subject—skilled experimenters, intelligent, educated, and interested. The investigation went on, and was completed as a preliminary investigation. You will find the records of that investigation complete in the first volume of the Report of the Board, so far as the investigation covered the study of the copper and tin alloys. You will find in the second volume of the Report, about to be issued, the records of the tests of copper, tin and zinc alloys. But the committee was stopped in the midst of its labors. It had completed a preliminary research on copper alloys, and it had made experiments on the other sections of its work, when the Board died, and the deductions to be drawn from the results obtained can only be drawn by studying the records as printed. The committee to whom it was intrusted had not time to work up the matter and put it into a concise form, as it should have been allowed to do. However, I have inserted in the second volume of the Report some of my own papers, in which I detailed some minor matters of investigation, and also gave a kind of summary of the results of the work, for presentation to the American Society of Civil Engineers. That society, as being the parent of the movement, seemed to be entitled to all the special information that could be given, and where any-

thing striking came out, it was put into the form of a paper and presented to that society, and is printed as a sort of appendix in the second volume of the Report of the Board. But a thorough, carefully prepared report has not been made.

Another interesting direction of study was that of orthogonal simultaneous strains; that is, strains produced in a metal simultaneously, but in rectangular directions. It may prove to be an exceedingly important direction of investigation. It is entirely untouched so far as I am aware; and when we laid down that matter on our programme we were unaware of any experiments at all ever having been made. In every structure you will find that these strains occur. I think nobody knows as yet what is the difference in the resisting power produced by a change of direction of the strains, or the result produced by simultaneous strains in different directions. You will find theoretical treatments of the case. Rankine gives a very beautiful one. But they are unsatisfactory simply because they are not corroborated by experience, and no engineer of experience and good sense would be governed by simple theoretical treatment until it had been fully corroborated by careful investigation and research. That remains to be done. You will find not a word about it in the Report of the Board.

Another line of study was the physical phenomena occurring during these tests of materials. It was proposed to make a special investigation of the physical phenomena accompanying the distortion and rupture of materials. It was going into a field entirely dark. Electrical forces arise, magnetic changes occur; anything else may occur; we do not know what occurs there. It was hoped that something would give us a clue to results in that direction. It may be that it might have revealed much; but nothing was done.

An investigation upon the effects of re-heating and re-rolling was proposed. The committee was instructed "to observe and to experiment upon the effects of re-heating and re-rolling, or otherwise re-working; of hammering, as compared with rolling, and of annealing the metals." To a certain extent that investigation was carried out, and incidentally by the committee on chain-cables: and you will find considerable very valuable matter in their report bearing on this point. In fact that committee accomplished more in side directions than either of the others. This is one of the things from which they did get

something. The fact that re-heating and re-rolling and re-working metals in various ways modifies their properties to a very important degree has been very long known. In fact we know that this change, included in all the phenomena of subsequent action in the manufacture of the iron, occurs even in the laying of a piece of iron out in the weather. I have lying among my specimens somewhere a piece of a rail laid down fifty years ago on the old Camden and Amboy Railroad, a rail rolled in Great Britain and sent to this country. That was, when it came here, a hot-short and a cold-short piece of metal. It lay on the track there for forty odd years when I got hold of it, and it appears to be still a good piece of metal, and some of it has been rolled into merchant bar and has made an excellent material. The effects of re-heating and re-rolling are very marked on wrought iron, and the effects of remelting on cast iron have been investigated by Rodman and others and shown to be important. That work remains to be done by the committee about to be formed.

Another matter to be studied was the constitution and qualities of steels produced by the modern processes. During the last twenty years have been brought into use many structural materials of an entirely different quality from what existed before that time. Bessemer and Siemens have given us metals that are gradually putting out of use the old metals. That committee were to investigate especially the qualities of these new materials. That was the direction for the work of that committee, and it was barely entered upon. You will find comparatively little in the Report about it, although you will find that the reports on some other subjects throw a considerable amount of light on this. But it is one of the most important of all these directions of investigation, and one upon which least is done.

Finally a committee was proposed to study the steels used for tools. You see the whole field was covered by these committees. An investigation carried on in this way should have been thoroughly complete. It would have occupied years, but the time would have been well spent, and the money expended would have been returned a thousand times over. There were a good many other directions of investigation opening to us, and some of immense importance. For example, one which does not appear here at all was the resistance of tubes and

flues to collapse. Gentlemen engaged in marine engineering and members of the Navy Department, especially, impressed on us the necessity of making investigations in regard to the resistance of flues. There is not a man who can tell you what is probably the resistance of a 42-inch flue made of $\frac{7}{8}$-inch iron. Nobody knows how that resistance varies with variation in length or thickness or diameter. Fairbairn's experiments were made on a comparatively small number of flues. He knew nothing at that time of welded flues. Here is a matter on which hundreds of lives are constantly depending and on which we know almost nothing. We simply know this, that these big flues, made of this thick metal, have not the strength that Fairbairn's formulæ indicate they should have. That is one of the things, then, that we did not even plan researches in regard to.

And so the Board laid out a plan of campaign such as I have sketched, and of course talked over a good many other things I am not able to speak of now. And when this Board had so planned its work; when it had begun its work; when its members had spent days and weeks, and months of time, giving health, strength, and almost life in some cases, and when they had just reached a point where work could have been done satisfactorily, the Board died, and that is the condition of the matter to-day.

Now the thing that ought to be done, in my opinion, is simply to bring that Board back to life; bring back its plan of campaign; bring back into existence all its methods of investigation. It had made a good start, and all that it did certainly ought not to be lost. If that cannot be done, let us get at the work again the best way we can. If we must go back to the beginning, let us do so; but at any rate let us get at the work once more and get more results. If you will take the trouble to look through these volumes, containing perhaps a thousand pages, of the work done by the Board, it will give you a very faint idea of what could be done by the Board properly supported by public sentiment, as well as by proper appropriations, and pursuing its work without embarrassment for a series of years. It should be done at once. The importance of the matter exceeds the importance of any measure of legislation now before Congress. Important as it is that we should have a new navy, I think the importance of a re-establish-

ment of this Board is vastly greater. I do not want to talk all the afternoon about this thing, and I have probably said enough to show you my interest in the matter, and what ought to be the interest of every man in the profession. I can speak of this matter without any self-interest, because it is a matter I do not feel I am likely to go into myself at all, and I can without the slightest embarrassment urge upon every member of the society that he endeavor with his utmost strength to bring about the formation of this Board.

MR. LE VAN: I would like to say that with cast iron, the form has as much to do with the strength of the structure as the material itself. The reason I mention that, is that Mr. Barr referred to a platen that he had made. I am satisfied that the internal strains of that platen itself were such that it was ready to break. Every projection that is put upon a column reduces its normal strength. I would like to ask whether form in cast-iron structures was to be taken into consideration.

PROFESSOR EGLESTON: Yes. It is one of the things to be taken into consideration.

MR. LE VAN: It seems of late years that engineers try to introduce all sorts of architectural designs in building machinery, very much to its detriment in regard to strength.

MR. BARR: After this platen was broken, of course we had to furnish a new one, and as the cotton press was built and in place, the new platen could not exceed in size the one that it was to replace; so that instead of running these two lines diagonally across the platen, from bolt to bolt, we carried them straight across lengthwise and put a heavier plate underneath, and then we put other plates in the centre. Now I believe that if instead of running those two pieces diagonally, as we did, if they had been run to a circle, it perhaps would have been better. Suppose in the centre we had made a cylinder, say twelve inches in diameter and run these diagonal pieces into that, leaving an opening in the centre and then going to the other side, it would have made a much stronger form; but that only opens the question again as to testing materials in actual sizes and conditions.

MR. PARTRIDGE: I presume there is not a man in our society who is not only thoroughly convinced of the necessity of the Board, but is heartily in favor of every effort that can be made

to get another commission in operation. The question arises now, what can we do individually? The joint committees and the local ones are doing all they can. In our form of government, we have to work in a very different manner from what would be necessary in the Old World. It will not answer simply to attempt to move it by taking hold of the heads of departments. We must commence with the constituencies, and every man here to-day can do effective work for the establishment of the commission by influencing the large manufacturers, the most influential in his district or the most influential men among his acquaintances. I understand that Professor Egleston has, or will shortly have, petitions to be signed. Now if every man among us will get copies of the petition, visit the manufacturers with whom he is acquainted, visit as many persons who are influential with his Congressman as he may be able; get their signatures, whether they are manufacturers or simply influential men in the district, and then send those signatures to Professor Egleston, he will be doing good work. When we have the public generally educated to the advantages of this—even if they are, as you might say, ignorantly educated—if they simply are in favor of it, because you tell them that it is the right thing, and they believe you—when we have got that, there will be little difficulty not only in getting the commission, but in keeping it alive.

Mr. Metcalf: I did not come here this afternoon to say anything. I came more to meet friends than anything else. But in reference to one or two matters that have come up—the platens that were spoken of—matters of that kind; also matters that the President mentioned, I would like to say that I have seen very large castings laid out of doors on a summer day and heated up by the sun, and then a thunder-shower would come and they would be broken through in the middle after the shower was over. I have seen large castings made of the finest iron that could be procured anywhere without reference to cost, split from one end to the other simply by a very small stream of water from a waste-pipe—splitting the iron without any reference to lines of resistance or anything else. It must be perfectly patent to every engineer here and every manufacturer, that it is utterly impossible for any private corporation or association to undertake to lay down the laws that govern cases of that kind. It must be done by the Government, for it

is going to cost an immense sum of möney to do it in such a way that it will be of any value at all.

In regard to steel, the portrait of our lamented friend reminds me that he spent many hours of his time with me in regard to preparing a series of tests of steel. The committee, which spent a good deal of time on that work, started out to get an iron manufactured from a well-known ore; procured samples of the ore; had it analyzed, and the iron manufactured by the Catalan process. That was analyzed carefully. The proportions of carbon were regularly increased up to 1½ per cent. Phosphates of iron were made, and the iron was tested with phosphorus from one one-hundredth of one per cent. up to one half of one per cent. Sulphides of iron were made, and the iron tested with them. An attempt was made to apply a similar system to the manufacture of iron, but that failed. And these samples were sent to this testing Board, and it was supposed that something would be obtained from all that work. The report of the chemist and the tester and the Board was that there was no relation whatever between the efforts that had been made to manufacture this steel and the final results obtained. That does not prove that the experiments were not made with the utmost care both by the manufacturers and by the Board, but it proved that one set of experiments has no value whatever when you come to lay down a law of strains or resistance of strains. And that matter of working out the alloys that can be found in steels can never be determined without thousands of experiments, and it is that simple reason that was the cause why every single engineer in this country and Europe who had occasion to criticise Dr. Dudley's experiments, criticised them unfavorably; because there were not a sufficient number of experiments made to prove the results. We all know the immense amount of work that has been done. We all know what we can gather here and there, out of the technical literature of this country and other countries, and yet the simple fact is to-day that the very best engineers in this country are going from one manufacturer to another to try to find out what they may use and what they may not use. There is not an engineer in this country that I have met, who says that he knows what he can get for a certain material, but he knows what he requires as learned from his experience and the experience of others. For these reasons I am firmly convinced that the only

way that engineers can ever get the information they need is through a public commission, maintained by the Government. And another reason, which I had occasion to mention before, and which I will repeat here, is the fact that it is impossible for engineers in their ordinary practice to get at the root of the matter. As you all know perfectly well, if an engineer goes to a manufacturer to obtain a certain lot of material of a certain brand, he will test it, he will know what test it will endure. But if he goes to the manufacturer and asks him how that material was made, and what it was made of, and how it was worked, the manufacturer will tell him very politely, but still in a way that he will understand perfectly well, that it is none of his business.

And the manufacturer is right. He is making a certain material which is known by its brand in the market, and has a certain value, and he feels that if he publishes his whole mode of manufacture that others will use all that they can of it, very possibly to his disadvantage. Now a Government Board can go to the same manufacturer and can say to him, "We want to get at certain results. We want to know the effect of reheating; the effect of working from different-sized piles. Now if you will take a certain raw material and give us samples to analyze, and give us the whole history of the manufacture, we will give you the physical and chemical results of it." No manufacturer will object to that. And in that way only is it possible for engineers to get at any information which will enable them to specify the proper modes of working these materials; and all of us who have been engaged in the manufacture of iron and steel certainly know that the mode in which these materials are manufactured and manipulated, controls more than perhaps the chemistry of them, the results that the engineer can obtain from them.

LXIII.

A STANDARD GAUGE SYSTEM.

BY

GEORGE M. BOND, HARTFORD, CONN.

In a paper presented at the May meeting of the society last year, a statement, or "report of progress" was submitted, showing the method adopted by the Pratt and Whitney Company, of Hartford, Conn., by which the question of practically establishing a standard for size gauges was to be scientifically determined, accurately subdividing the Imperial yard into feet and inches and fractional parts of an inch, and describing briefly the extent to which was carried the scientific research found absolutely necessary for such an undertaking; it remains now to present to the consideration of those who may be interested, a statement of the results proceeding from the practical application of all the thorough, conscientious investigation of Professor Rogers, of Harvard College Observatory, whose invaluable experience and professional services, in obtaining for the company the transfer and subsequent subdivision of the British yard, gave the foundation for what has been accomplished, enabling the company to feel warranted in earnestly inviting an inspection of the means now available for the production of standard sizes, and asking for it the indorsement of the engineering profession, should it be found worthy of such necessary support.

The comparator referred to in the previous paper, has been placed in position upon brick piers in a room outside the main building, erected especially for it, and is comparatively free from the jar and tremor of the machinery, even unaffected by the jar of passing trains, the tracks of the New York, New Haven and Hartford, and of the New York and New England Railroads being quite near, the rigidity of the instrument and the excellent workmanship in its construction preventing any perceptible vibration during an observation, even when the high-power microscopes, magnifying 150 diameters, are used.

The illumination required in using these microscopes is per-

fectly attained by reflection, using a plate-glass mirror placed outside of the window of the comparing room, at an inclination of 45 degrees, giving clear diffused light, cloudy weather even improving the general effect, as the light is then whiter than that reflected from a clear blue sky, and the lines on the standard bar, as seen through the medium of the Tolles' illuminating prisms with which the objectives are fitted, are clearly and sharply defined at any time during daylight, and in any position of the microscope plate; by thus avoiding the use of artificial light and consequent effect of a variable temperature, far more satisfactory results are obtained.

The investigation for the determination of the necessary corrections for errors due to horizontal or vertical curvature of the path of the microscope plate, has shown conclusively the unexcelled workmanship in the construction of the comparator; as an instance of how slight these errors really are, it was found after repeated observations, the means being carefully collated, that the horizontal curvature, *i. e.*, the bending sidewise of the cylindrical guides or ways upon which the microscope plate slides, at the part investigated, was that having a radius of *eleven miles*, and a consequent correction to be applied of about one ten-thousandth of an inch in eighteen inches, the latter distance referring to the position of the measured standard when placed either side of the line of motion of the centre of the microscope plate, moving between fixed stops, and which is the constant quantity to which is referred the subdivisions of the standard bar; as the microscope is usually within one inch, rarely over two and a half, from the centre line of the stops or caliper jaws between which the end measure pieces or the cylindrical gauges are placed, this correction evidently becomes too small to be applied practically, within the limit of a six-inch gauge; for a foot or a yard it would become necessary, as the variation of the chords of the subtended arcs then becomes quite perceptible. The errors due to inequality of temperature in the standard steel bar and the hardened steel end-measure gauges must be carefully guarded against, the latter effect being far more important, practically, and often very misleading. In the case of a four-inch hardened steel end-measure gauge experimented upon, the coefficient of expansion being nearly one one-hundred thousandth of its length, one degree of change of temperature

from that maintained in the reference bar introduces an error of about one twenty-five thousandth of an inch in the total length, and hence, as a change or inequality of five or even ten degrees might be easily overlooked, the four-inch gauge would be found to be from one five-thousandth ($\frac{1}{5000}$) to one twenty-five-hundredth ($\frac{1}{2500}$) of an inch too short, when equality of temperature is restored, when it is asserted that an actual variation of so minute a quantity as *one thirty-thousandth* of an inch, and even less, can be readily detected by any tool-maker familiar with the use of an ordinary micrometer or a close gauge, the importance of keeping *within* this limit is apparent,—of course, this shortening effect is not so marked in smaller sizes, still the ratio is the same, and this error must be carefully avoided.

The subdivisions upon the six-inch hardened steel standard bar have been carefully investigated upon the new comparator, to determine how nearly these inch spaces equal each other, the total length of the four inches which are ruled upon this six-inch bar being *exactly standard* at 62 degrees Fahrenheit, according to the preliminary report of Professor Rogers, received December 1st, 1881, and in this report, the results obtained by him, determining this relation of the inch spaces to each other, were found to agree closely with the results obtained by me, as the following comparison will show, these minute corrections being necessary in accurately determining the subdivisions of the Imperial yard, which they represent:

Corrections.	Prof. Rogers' Report.	Results obtained.	
Total 1 inch, *add*, . . .	0.000008	0.000008	($\frac{1}{36}$ yard.)
Total 2 inches, *subtract*, . .	0.000026	0.000027	($\frac{1}{18}$ ")
Total 3 inches, *subtract*, . .	0.000005	0.000006	($\frac{1}{12}$ ")
Total 4 inches, ...	correct	correct	($\frac{1}{9}$ ")

(The errors being counted from the first line.)

The results given in the last column are the *means* of a number of observations, taken at different times and under various conditions of temperature, etc., and cover a period of about four weeks, the final results having been obtained December 31st.

The value of the divisions of the micrometer employed was carefully determined in order to reduce them to the same unit used by Professor Rogers, and was found, using the microscope marked "B," to equal $\frac{1}{58500}$ of an inch (0.000016 nearly).

When it is considered that the two results were obtained under different conditions, using different microscopes, and with comparators differing in construction, the correctness of the *principle* upon which the comparison is founded, certainly needs no other proof.

The method of obtaining this relation of the separate inches upon the six-inch standard, was referred to in the former paper, and is that of comparing each inch with a constant distance moved over by the microscope plate between fixed stops, a constant pressure of contact being obtained by the use of electro-magnets, the separate inch spaces being thus referred to an *invariable* quantity or distance, and their relation to each other consequently determined.

To explain more fully this operation, the method adopted is as follows: A series of readings are taken at the zero or initial line of the first inch space, using the micrometer referred to, the microscope plate being held firmly against the fixed stop by the electro-magnet; the microscope then moves with the sliding plate until the latter is in contact with the other fixed stop, and held by the electro-magnet, the plate having moved as nearly an inch as it may conveniently be done,—generally a little more than an inch, in order to have the *sign* of the reading always the same,—from three to five readings of the micrometer are then taken at each position of the microscope, and the order reversed, to eliminate possible error; the first inch is thus compared with a fixed quantity, and the same operation repeated for the remaining inch spaces.

The difference between the distance moved by the microscope plate and the distance between the defining lines representing inches, is found by subtracting the *means* of the readings obtained, and thus eliminating the possible error of any single observation.

The following is a series of micrometer readings, and comprises the means of all the observations by which the corrections of the separate inches were obtained, illustrating the system adopted, and which has been used invariably by Professor Rogers in his investigations of the subdivisions of the yard and meter bars, now in the possession of the Pratt and Whitney Company.

COMPARISON OF INCHES.

	L.	R.	L.	R.	
	58.1	65.8	58.0	65.5	Reverse order.
1st inch, . . .	58.6	66.0	58.1	65.8	
	58.5	65.4	58.0	65.8	
Mean, ...	58.4	65.7	58.0	65.7	
	58.0	65.7			
Mean, ...	58.2	65.7			

R − L = + 7.5 divisions of micrometer.

	L.	R.	L.	R.	
	56.2	65.8	55.4	65.4	Reverse order.
2d inch, . . .	55.6	65.8	56.0	65.4	
	56.2	66.0	55.4	66.0	
Mean, ...	56.0	65.8	55.6	65.6	
	55.6	65.6			
Mean, ...	55.8	65.7			

R − L = + 9.9

	L.	R.	L.	R.
	55.0	63.0	57.0	63.0
3d inch, . . .	55.8	63.0	57.0	63.5
	55.7	63.6	57.0	62.8
Mean, ...	55.5	63.2	57.0	63.1
	57.0	63.1		
Mean, ...	56.3	63.1		

R − L = + 6.8

	L.	R.	L.	R.
	57.4	64.3	56.0	64.2
4th inch, . . .	57.8	64.8	56.1	64.5
	57.8	64.8	56.8	64.5
Mean, ...	57.6	64.6	56.3	64.4
	56.3	64.4		
Mean, ...	56.9	64.5		

R − L = + 7.6

Correction Σ

+ 7.5 + 0.45 + 0.45 = correction for first inch.
+ 9.9 − 1.95 − 1.50 = correction for first 2 inches.
+ 6.8 + 1.15 − 0.35 = correction for first 3 inches.
+ 7.6 + 0.35 ± 0.00 = correction for 4 total inches.

Mean + 7.95

The differences of the observed inch spaces with respect to the constant quantity obtained by the motion of the microscope plates, are added and their means taken, from which the

corrections are determined with the proper signs, to determine the total error counting from the first line. These corrections are added, the final result being evidently zero, the column under "Σ" showing this algebraic sum.

It may be appropriate here to state that the six-inch bar upon which these four-inch spaces are traced, is a standard which is, without doubt, the only hardened steel *line-measure* bar in existence which is exactly one-ninth part of the Imperial yard at 62 degrees Fahrenheit, and Professor Rogers guarantees it as such in his report, before referred to.

In order to apply these subdivisions, which include all sizes, from one-sixteenth of an inch to four inches, varying by sixteenths, to a practical form, fixtures have been provided and are in constant use, for reducing to *end* measure the distances thus accurately spaced; a caliper attachment has also lately been added, from plans proposed by Professor Rogers, by which the diameter of existing cylindrical gauges, as well as the length of end-measure pieces from one-sixteenth of an inch to six inches may be tested with the same precision that characterizes the investigation of the linear spacing of the standard bar, also providing means for a rigid inspection of finished gauges before they leave the works, thereby insuring uniformity.

To illustrate how nearly alike two pieces may be made, two standard inch end-measure gauges were worked down under the microscope, independently of each other, using the lines upon the ruled standard reference bar and the fixture referred to, which, when compared with each other by the most careful tests, using close or "snap" gauges, and tested thus by toolmakers experienced in work requiring the utmost practical precision, neither piece could be singled out as the larger, the effect of unequal expansion caused by temperature being avoided during the test. Under the microscope, both pieces were found to be exactly alike by a *single* observation, while the comparison by a series of readings of the two pieces showed a mean difference of one-tenth of a division of the micrometer, and when it is remembered that one division has a value of only $\frac{1}{88500}$th of an inch, the duplication, it may be assured, is certainly satisfactory, and is clearly within a practical, if not a theoretical limit of accuracy.

Having thus the means for closely reproducing established sizes, and no possible wear occurring to the bar from which

these sizes are taken, the accurate duplication becomes a comparatively simple operation.

In order to produce standard work within the limit of a yard or a meter, there has been furnished by Professor Rogers, two steel yard and meter bars, referred to in the previous paper, one of these bars tempered, the other being left soft, but having hardened steel plugs, which are adjustable, for the purpose of bringing the surfaces into focus under the microscope; upon these hardened plugs the lines are ruled, both bars having line and end measure, thus providing means for testing the accuracy of the pitch of screw threads of any desired length, and for standard length gauges up to thirty-six inches, or to a meter.

The coefficient of expansion has been determined for each by Professor Rogers with an exactness never before attained, as stated in his report, and also the relation, at 62° (F.), between these steel bars and the two bronze standards, both of which are line measure (the latter are described in the previous paper referred to), so that gauges of any size may be made almost independently of temperature, other than the care required in keeping this condition as nearly uniform as possible for both the reference and the measured bar during the time of the transfer, or the determination after having been transferred.

The subject of accurately producing standard leading screws is receiving its share of attention, and those who use micrometers will readily understand its bearing upon the precision with which they may be made, and how unsatisfactory because of the necessary corrections to be applied in many instances, even when standard at some one part of the divided head—a uniform lead or pitch of the screw, however much may be the total error (within a reasonable limit), making a great improvement in their construction.

Besides a complete set of end-measure gauges, varying by sixteenths from one-quarter to four inches, there is now ready for inspection a complete plant, consisting of tools and fixtures for producing the standard United States or Franklin Institute thread gauges, every detail having been carefully considered, and every difficulty overcome in the operation for perfecting, not only these standard gauges as to size, but the pitch of the thread, the correct angle, and the width of flat at the top and bottom of the thread; the accuracy with which these details

are carried out is now open to the inspection of all who may be interested, and rapid duplication by *machined* work is now an assured success.

It is with the confidence that the "bottom" has finally been reached, that warrants the Pratt and Whitney Company in thus inviting a thorough inspection of the means available, and the methods employed, in producing standard gauges, and earnestly desiring an impartial verdict as to its accuracy and practicability, whether or not, the system as adopted and carried out, has any real merit upon which the confidence of those using gauges for interchangeable work may be safely based.

DISCUSSION.

PROFESSOR ROBINSON: This paper is of the highest merit and of the greatest possible interest to members of the society, and it is a matter of great satisfaction to the mechanical engineers of this country that there is some one who is able to take hold of this question and treat it so ably as it has been treated; and inasmuch as the methods and results, as stated by the reader, are laid open for inspection by others, I think it is due, in consideration of the amount of effort and expense which has been given to this matter, that the society, as a matter of duty, should appoint a committee to avail itself of the privileges offered of investigating this, and of making such a statement regarding it as will be found advisable; and undoubtedly this is a thing which the society will be willing and anxious to indorse in every particular as a standard of the country. For one, I should be glad to see a committee appointed to give this method the attention it deserves

PROFESSOR EGLESTON: I do not know whether the members of the society are familiar with the fact that in 1875 the Institute of Mining Engineers appointed a committee on standard gauges, and that committee came to just exactly the conclusion which is expressed here, that diameters or linear measures ranging in fractions of a millimeter or an inch were the only gauges which were standard or could be standard. It is a peculiar gratification, since a large part of the work fell to my hands, to see that idea so fully sustained. It is a matter of a great deal more importance than perhaps would appear just now. I have heard recently that the English engineers are again agitating the question of standards, and are going back to the old caliper

idea. I think this is really a retrograde movement. Most of you may know the fact, but we discovered in the course of our investigations, that in a package of a dozen standard gauges, so-called, of the fixed patterns, no two of them will be alike.

THE PRESIDENT: I suppose the members would be interested if Mr. Pratt would tell us how they went to work in this undertaking. Mr. Pratt told us the story at Hartford, but many gentlemen are here to-day who were not with us then, and I presume it would be very interesting to all to know how Messrs. Pratt and Whitney were led into this prolonged, expensive, and nice investigation.

MR. PRATT: I will relate the story in the briefest possible way. We were called upon to furnish a set of standard thread gauges, and of course the first thing to do was to get the sizes, and upon examining the different makes of gauges we found no two sets alike, and we were forced to commence, as we thought, at the bottom, and at that time, in sending about a foot-piece that we had obtained, we found that those investigating it did not agree upon its value. Among others Professor Rogers was applied to, to investigate the foot-piece, and he had quite a struggle over it with some of our prominent manufacturers of gauges. They could not agree, and Professor Rogers took it upon himself, at his own expense, to go to Europe, and go to the bottom of the thing. He visited the best authorities in Europe, and spent four months there in investigation. After we had obtained the services of one of the graduates of the Stevens Institute, and in connection with Professor Rogers, we constructed two comparators, one of which Professor Rogers has himself, and one of which we have; they being exactly alike. After Professor Rogers returned he investigated the foot-piece, and found it to be about what he had found it to be before, and then, after the new comparator was finished, he found his statement verified. Previous to this time, fortunately, Professor Rogers had been for several years constructing a ruling machine, and he had it completed about this time. We have gone very carefully into this thing. I do not feel egotistic about it at all. What we want is that every one who is interested in the matter, every society that takes any interest in it, should come and examine our methods and our measurements. If they are good, let us have a standard. If they are not, let us throw them away. It has cost us probably twenty thousand dollars

to-day, and I am willing to throw it away if anybody can show us better. We want a standard, and I will not stand in the way of any one else who has a better machine. I feel very much interested in the subject, myself; and I think we shall succeed in what we have undertaken.

LXIV.

THERMODYNAMICS OF CERTAIN FORMS OF THE WORTHINGTON AND OTHER COMPOUND PUMPING ENGINES.

BY

S. W. ROBINSON, PROF. MECH. ENG., OHIO STATE UNIVERSITY.

The present object is mainly an investigation from a theoretical stand-point of such compound steam-engines as effect the principal part of the expansion of the steam in the act of exhausting from the high-pressure cylinder into a receiver, from which receiver the low-pressure cylinder is supplied with steam. The paper is, however, not confined to this, the Woolf compound with receiver; but the Woolf without a receiver in tandem form, is briefly considered for purposes of comparison.

The high-pressure cylinder is supposed to take its steam at constant pressure from a boiler during its full stroke, then to exhaust into the receiver. The back pressure is the pressure of the steam in the receiver, which will be somewhat variable according to relation of sizes of receiver and cylinders. The low-pressure cylinder steam supply will also vary somewhat in pressure according to pressure in the receiver. This cylinder exhausts into the air, or into a condenser; the back pressure due to which is assumed constant in the calculations.

An engine of the kind now considered is shown in Fig. 16, in which the disparity in sizes of cylinders is plainly shown. The "tank" or receiver is situated below the cylinders, and it is some eight or ten times as large as the steam cylinder.

A good idea of the sectional view of this engine can be obtained from Fig. 14, which would be made identical by removing the large cylinder *B* from one side, and the small cylinder *A* from the other side, then placing the remaining two cylinders

opposite each other, and directly over the receiver, or "tank." The valve-gearing, condenser, etc., are alike in both.

PRESSURE VARIATION IN RECEIVER.

The amount and variation of the pressure in the receiver is a complex quantity, depending as it does upon: 1st, the size of the receiver; 2d, upon the sizes of the two cylinders; 3d, upon the mode of working the valves; and, 4th, upon the relative motion of the two pistons. A still greater complexity arises when more than two pistons are employed in one machine, unless two work as one. In the present paper, investigations are limited to a comparatively few cases: as to pistons, only two; and one receiver.

THE PISTON MOVEMENTS.

As to the piston movements three are possible, viz., 1st, they may have entire independence; 2d, they may be limited to an equal number of strokes per minute, with initial points in certain relation; and, 3d, they may be further limited by periods of tarrying. The latter is the case with the Worthington pump.

THE VALVE MOVEMENTS.

As to the valve movements, four are possible, each differing from another in efficiency. Two are selected as special objects for investigation here, viz., the one with the lowest efficiency, and that with the highest. But all these efficiencies approach, and, finally, have a common value as the receiver is enlarged to infinity. For this latter and special case the formulas are much simplified. But as results of much interest and value are obtained from the general formulas, the latter will be deduced and applied. One important service of the general formulas is to point out the fact, that with a certain mode of working the valves, a comparatively small receiver gives a higher efficiency of steam than a larger, or infinite one.

The engine, with two pistons and one receiver, is briefly shown by diagram in Fig. 6, where *b*, *d*, are admission valves for high steam, into small cylinder; *e*, *f*, exhaust valves from the small cylinder into the receiver; *g*, *h*, admission valves from the receiver to the low-pressure cylinder; and *j*, *k*, exhaust valves from the low cylinder.

The action of the engine, except where mentioned as otherwise, is considered as alternating between the two pistons; that is to say, one piston stands still at the end of the cylinder, while the other makes its stroke, and conversely. This is the third above mentioned.

The diagram will enable us to indicate the fact of different ways for working the valves. For instance: 1st, suppose *b* and *f* open, *c* and *d* closed, piston *H* moving, and piston *L* standing at end of cylinder. Then with *j* and *k* closed, *g* and *h* may be either opened or closed. If closed, the steam from *f* accumu-

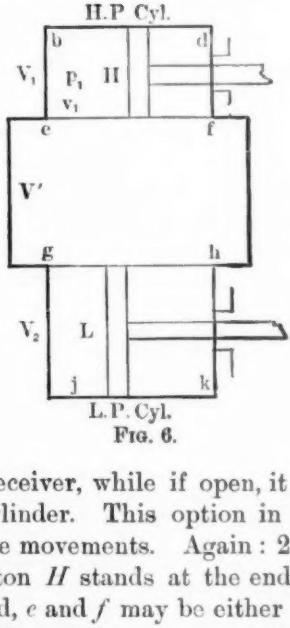


FIG. 6.

lates only in the receiver, while if open, it flows into both the receiver and *L* cylinder. This option in the valves *g* and *h* occasions two valve movements. Again: 2d, suppose piston *L* moving, while piston *H* stands at the end of the stroke, then with *b* and *d* closed, *c* and *f* may be either opened or closed, a second option which occasions two separate valve movements, for this side of the engine. In the combined action of both sides, it appears from the fact that these options are independent of each other, there result four possible valve movements.

THE VALVE MOVEMENTS INVESTIGATED.

Two cases will now be investigated and compared. They are shown in Fig. 7. Both suppose two pistons and one receiver, each with alternate rest and motion of pistons as in the third mode of piston action mentioned above. The first case

is for the least, and the second for the most efficient valve movement.

THE TWO VALVE MOVEMENTS.

In the 1st, and also 2d, of Fig. 7, the engine is represented in the four relations necessarily undergone for completing a cycle of operations. For instance in 1st, we have piston *H* moving while piston *L* stands, then *H* stands while *L* moves, next *H* moves opposite to the first as *L* stands, and finally *H* stands as *L* moves, contrariwise to that of its first stroke. The next move is the same as the first, and thus they continue in repetition. Piston-rods are shown by arrows, which indicate direction of motion. Broken arrows mean standing still.

As to these piston motions: the 2d part of Fig. 7 is like the first, the difference being confined to the valve movements and steam action.

In Fig. 7 all open valves are indicated by arrows. Feathered arrows are put for valves necessarily open, while naked arrows are at valves in option. In the light of these remarks, the valve movements of 1st and 2d may be traced throughout, also steam action. For convenience let the four relations of Fig. 7 be designated as *A*, *B*, *C*, and *D*.

Then in 1st: for the *A* relation we have *H* moving with high steam on one side and exhaust on the other. These are necessary conditions while *H* moves, and hence the arrows are feathered. The exhaust, however, is shown as into the receiver not only, but the *L* cylinder as well, because the valve to the *L*-cylinder is open. But that valve might be closed when the steam would be confined to the receiver with a more rapid rise of pressure. The latter condition is shown in the *A* relation of 2d, hence this arrow is left naked.

Again in the *B* relation, the *H* piston is standing while *L* is making its stroke. The valve between *H* and the receiver is closed in 1st, or it may be open as in 2d, and hence the arrow is featherless as shown.

These references suffice to explain the *C* and *D* relations also, so that both parts of Fig. 7 are understood. Thus in Fig. 7 are exhibited two separate valve movements and four relations of piston motion for each. These will be considered separately.

Respecting the size of the receiver, it is evident that it may

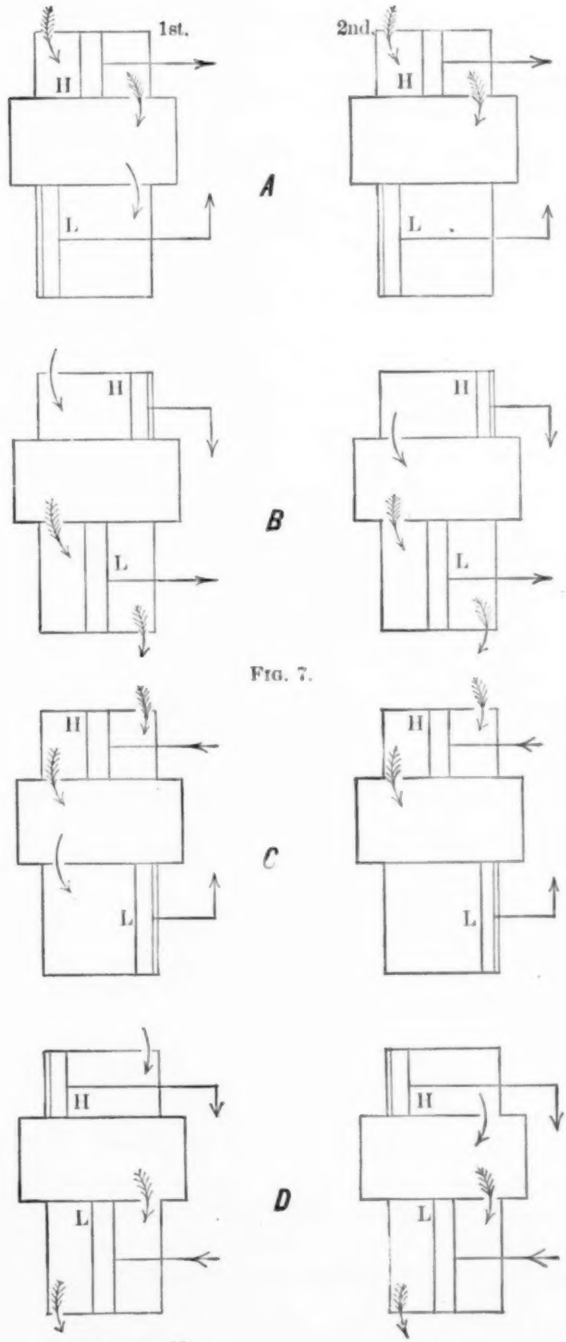


FIG. 7.

be assumed at pleasure, finite or infinite. We will first take it finite.

I. SOLUTION FOR THE FIRST VALVE MOVEMENT OF FIG. 7.

Before making statements of steam action it will be necessary to know specifically the condition of the steam at every point as it passes through the engine. For the 1st part of Fig. 7, the complete diagram of steam ac'ion, for continuity of engine movement, is given in Fig. 8.

Let V_1 = volume of the high-pressure cylinder, V_2 = volume of the low-pressure cylinder, and V' = volume of the receiver. These volumes are shown on the diagram in their proper relations. Also the absolute pressures P_1 of the boiler, P_2 of terminal expansion, and P_3 of the exhaust, are shown. Other pressures will be indicated according to lettering of diagram, as, for instance, $P_1 = P_g$ being the pressures at the points I and G. In short, the pressures and volumes are represented by vertical and horizontal distances respectively, with A for the zero or origin.

The Complete Diagram and Indicator Cards.

Now, referring to 1st of Fig. 7, we see that in the A relation the low-pressure or L-piston is standing at the end of its stroke, and with the valve between that cylinder and the receiver open; the steam that made the last L-stroke being retained. Hence the L cylinder and receiver both together are serving as receiver, while the high-pressure or H-piston is making its stroke and forcing the steam from the H-cylinder into the receiver. The H-piston is moved by steam from the boiler, the same being admitted at full pressure P_1, and full stroke.

Now in Fig. 8, FL represents this high-pressure line of P_1, while KG represents the compression line of the H-piston stroke. It is to be observed that at the initial return of H, the volume is $AC = V_1 + V_2 + V'$; and at the end, it is $AD = V_2 + V'$.

Next, in the B-relation of 1st of Fig. 7, the valves of L are reversed, as H completes its stroke, the steam in the L-cylinder being exhausted. In Fig. 8 this exhaust is shown by a cutting off of the steam GI, and leaving only that in the receiver, of volume $V' = AE$, to act upon the L-piston.

The *H*-piston now stands while the *L*-piston makes its stroke with a change of active steam volume from V' to $V' + V_2$; and producing the expansion line *IH*, Fig. 8. Next the valves of *L*, Fig. 7, remain, while the valves of *H* reverse; so that the *L*-piston stands while the *H*-piston moves as in the *C* movement.

Now as the valves of *H* reverse, the high steam exhausts into the receiver and *L*-cylinder together, giving the expansion line *FJ* for the high steam, and the compression line *HJ* for

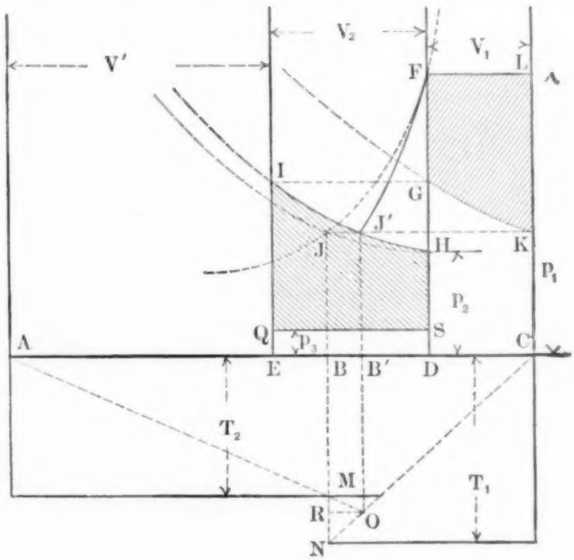


FIG. 8.

the low steam, till both arrive at a common pressure at *J*. The expansion line *FJ* is to be drawn with *C* as the point of zero volumes and pressures; while *HJ* has *A* for the like point. Here the steam, isodynamically brought down from P_1 at *F*, will be hotter than that brought up from P_2 at *H*; and as they commingle, the volume *JK* decreases by giving up heat, and the volume *AB* increases by receiving that heat. But as the same weight of steam must necessarily be exhausted from the high cylinder as from the low at a stroke, it follows that the steam *JK* introduced must have equal weight with the steam *GI* exhausted. Hence the volume *JK* must

shrink by cooling to some volume $J'K$, such that J' lies on the expansion curve IH; because when AC is compressed along KG to AD, then $J'K$ must compress to GI, and AB' to AE. The curves KG and $J'I$ are of like sort, with the point A for the zero of pressures and volumes.

Now H commences its stroke with a back pressure $P_3 = CK$, and the volume $AC = V_1 + V_2 = V$. At the end of the stroke this volume has been reduced to AD, giving the compression line KG. At the end of this stroke the valves of L are reversed, causing the immediate exhaust from L of the volume $GI = V_3$, when in the L-stroke the expansion curve IH, etc., is formed as before.

Thus it appears that $FGKL$ is the indicator card of the H-cylinder, while $HIQS$ is the card for the L-cylinder. The work done by these cylinders will be proportional to these areas.* The back pressure is $EQ = P_5$.

Nature of the Expansion and Compression Lines.

Having traced out the action of the engine and of the steam as it is worked in it, we are prepared to inquire into the specific nature of the various lines of the complete diagram, Fig. 8, from the standpoint of thermodynamics. Thus the compression curve KG is adiabatic, and such that if the steam is saturated at K, it is superheated at G by the compression. Hence, as the steam will be shown to be not far from saturated at K, this curve is an adiabatic for superheated steam. The same is true of $J'I$, because as K is compressed to G, J' is compressed to I. After the exhaustion of the volume GI, the curve IJ' is retraced by expansion with the same steam as was just compressed along $J'I$. But with $J'H$ the case is to some extent different, before explaining which, we must consider JH and JF. With respect to the latter, it is to be observed that at the end of the stroke of the L-piston, the volume $V' + V_2$ is ready to receive the high-steam exhaust from the H-cylinder. Here the low-steam pressure is $DH = P_2$, and high-steam pressure $DF = P_1$; while the volumes are $V' + V_2 = AD$, and $V_1 = DC$, respectively. Now as the valve from H to the receiver opens, these two portions of steam

* Cards actually taken with the indicator, however, have equal lengths. When modified to lengths FL and QS the proportion is true.

coalesce * into a common body, whose volume is simply the sum of the previous partial volumes; that is to say,

$$(V_2 + V') + V_1 = V_1 + V_2 + V';$$

and the resulting pressure is BJ. In this act no exterior work is performed by the mass of steam in the volume AC, because, for the instant during which this commingling occurs, the pistons of the engine do not move perceptibly. This act is therefore governed by *Hirn's law;* that is to say, because no external work is done during the change, the internal energy of the mass of steam remains constant. The curve representing this action is the so-called *isodynamic curve.* Hence the pressure BJ is to be found at the intersection of two isodynamic lines FJ and HJ; the first representing the isodynamic expansion of the volume V_1, and the second, the compression of the volume $V' + V_2$.

Though these curves serve to determine the point J, or resulting pressure BJ, yet it is to be understood that they do not represent the operations which actually take place in the two portions of steam, because the low steam is in reality compressed adiabatically from H to J', and the work $B'DHJ'$ performed. This work is performed by the expansive action of the high steam while actually expanding along some line FJ', and not FJ. This curve, however, will lie above the adiabatic through F, because in expanding along FJ' the steam is not doing its full work, the work actually done being only $B'DHJ'$, instead of an area extending fully up to the expansion line. Hence, J' instead of J, represents the actual resulting point of pressure.

Now the points J and J' are expected to be *very nearly* in a horizontal line, but may not be exactly so for several practical reasons. The expansion $J'H$ will probably be mostly adiabatic below the saturation-point, the point of change from superheat to supersaturation lying somewhere on $J'H$, but not far from J'. Much of the supersaturation moisture due to this expansion may be precipitated while the L-piston tarries

* This, however, is only partially true, since some of the steam remains in the H-cylinder till forced out through the open valve into the receiver during the return stroke. Though the pressure is common, yet the temperature and density of that remaining in the cylinder will probably differ somewhat from that in the receiver.

at the end of its stroke, so that the compression heat of HJ' acts at a disadvantage in re-evaporating that moisture. The moisture thus precipitated may accumulate in the receiver as water, and require to be drawn off by a cock. To show that at the end of the stroke IH the steam is necessarily below the saturation-point, we observe that KG and $J'I$ are counter-actions which offset each other, as already explained, and hence have no influence on the final condition of saturation. Now, referring to the isodynamic lines, the expansion FJ gives rise to superheat while the compression HJ occasions condensation. These actions nearly compensate each other, because, though the intensity for FJ is greater than for HJ, yet the quantity of steam concerned in JH is greater: assuming that these exactly neutralize, then the saturation-point lies very near to J', and below it if supersaturation moisture is precipitated in the receiver.

It appears, therefore, that the expansion line IH is of two kinds, viz., from I to some point near J' it is adiabatic for superheated steam, while from the latter point to H it is adiabatic for supersaturated steam.

Equation for Expansion and Compression Lines.

In looking over the several forms of curve shown on Fig. 8, it appears that there are three, all of which are provided for in the convenient approximate equation

$$\left.\begin{aligned} Pv^x &= \text{constant} = P_1 v_1^x \\ \text{or,} \quad \frac{P}{P_1} &= \left(\frac{v_1}{v}\right)^x \end{aligned}\right\} \qquad (1)$$

As this equation is approved for ordinary purposes by high authority, it will be adopted in the present investigation.

Table of Values of x, and Authority.

Values of x =	Adiabatic Expan. Initial Saturation, ∞. m	Curve of Saturation. s	Adiabatic for Superheated Steam. a	Isodynamic for Superheated Steam. n
Rankine, . . .	$\frac{10}{9} = 1.11111$	$\frac{17}{16}$, and 1.0646	1.3	Not given.
Cotterill, . . .	$1.035 + \frac{\infty}{10}$	" "	"	Bet. s and 1
Zeuner, ...	" "	1.0646	$\frac{4}{3} = 1.3333$	1.0456
Röntgen, . . .	" "	"	"	"

This table and (1) will give us the equation of any curve desired. Accordingly we find

$$\left.\begin{array}{llr} \text{Curve } FJ & \text{isodynamic and } x = n & \\ \quad \text{"} \quad HJ & \quad \text{"} \quad \text{"} \quad \text{"} & \\ \quad \text{"} \quad GK & \text{adiabatic for superheat and } x = a & \\ \quad \text{"} \quad JJ^1 & \quad \text{"} \quad \text{"} \quad \text{"} \quad \text{"} & \\ \quad \text{"} \quad J^1H & \quad \text{"} \quad \text{initial sat. } x = m. & \end{array}\right\} \qquad (2)$$

In these we not only have authority for a variety of values of x, but in m the "steam quantity" ∞ suggests that the value of x may be determined even by estimation from such facts as may effect x. Accordingly, for an expansion where only partial work of expansion is performed, x may be found to lie between $\frac{4}{3}$ and 1.0456 for superheated steam. When $\infty = 1$ we have $x = 1.135$. It is to be observed, however, that the form of curve, according to equation (1), is dependent on the value of the exponent, so that the general equations may be considered as suitable for any forms of these lines.

Insignificance of JJ'.

For the difficulty and complexity resulting from the attempt to account for the change JJ' in the general equations, we will first examine that quantity to see if worthy of that trouble.

Regarding H as a point of intersection of the adiabatic and isodynamic curves $J'H$, and JH, we may find JJ' by aid of (1), on the supposition that it is wholly due to the deviation of these curves, thus:

$$\frac{P_3}{P_2} = \left(\frac{V_2 + V'}{V_3}\right)^n \text{and } \frac{P_3}{P_2} = \left(\frac{V_2 + V'}{V_3'}\right)^m$$

Solving for V_3 and V_3', and taking their ratio, we have

$$\frac{V_3'}{V_3} = \left(\frac{P_3}{P_2}\right)^{\frac{1}{n} - \frac{1}{m}} = \left(\frac{P_3}{P_2}\right)^{\frac{m-n}{mn}} = \left(\frac{P_3}{P_2}\right)^{.0753},$$

where m is taken at 1.135.

The volumes V_3 and V_3' are reckoned from the origin A, Fig. 8.

As an example, take $V' = V_2 = 2\,V_1$, the receiver being unusually small, then the value of $\frac{P_3}{P_2}$ = about $\frac{1}{3}$. Introducing this and solving, we find,

$$\frac{V_3'}{V_3} = 1.022 = \frac{V_3 + JJ'}{V_3} = 1 + \frac{JJ'}{V_3}$$

whence

$$JJ' = .022\ V_J$$

from which it appears that the greatest practical value of JJ' is about two per cent. of the volume V_J, or of AB.

Again, take what may be a moderate value of $V' = 4\ V_2 = 8\ V_1$ then a sketched diagram will show that $\frac{P_J}{P_2}$ = about $\frac{9}{8} = 1.125$, whence

$$\frac{V_J'}{V_J} = 1.009$$

or

$$JJ' = .009\ V_J,$$

which is less than one per cent. Hence it appears that that part of JJ' which is due to the deviation of these curves, may probably be neglected in practice without serious results.

Should it be desirable to account for JJ', it will perhaps be most convenient to do so on the drawing-board, by laying off the volumes and pressures, and drawing the curves by trial so as to fit. In such case the preliminary diagram may be drawn by aid of an approximate solution afterwards given, for which $x = 1$ in Eq. (1).

To Account for JJ' on the Supposition of Heat.

In this case the drawing-board may be preferred. Use temperatures and a diagram, as shown in the lower part of Fig. 8. As the temperatures for the isodynamic lines through J are each nearly constant, let the absolute temperatures τ_1 and τ_2 of the steam at admission and at the end of $J'H$ be laid off downward, as shown. Draw lines to M and N, meeting JMN. Then draw straight lines AMO and CNO, giving the intersection O. Then the line through O parallel to NJ should give the point J'. The diagram ANC depends upon the law of Gay Lussac, relating to volume and temperature, for constant pressures in gases, viz., by symbols

$$\frac{v}{\tau} = \frac{v^1}{\tau^1}.$$

In superheated steam this very nearly holds true. In the diagram the application is $AB : BM :: RO : RM$, and $CB : BN :: RO : RN$. The two portions of steam are first supposed reduced to the common pressure P_J, by the isodynamic,

or nearly constant temperature expansion FJ, and the like compression HJ. The volume BC then has the temperature τ_1 of P_1, and the volume AB the temperature τ_2 of p_2. The change JJ' is that by which the portion BC shrinks, and of AB expands, while the temperatures τ_1 and τ_2 merge into one temperature, $\tau_j = BR$.

Repeated trials should be made until JJ' is a horizonal line from the intersections J of the isodynamics to the adiabatic IH, and with $J'K$ and GI also horizontal.

But as the correction to the volume $AB = V_j$ is usually less than one per cent., it is probable that the discrepancies in results of efficiency or duty of engine due to it will be too small to merit serious consideration.

Hence, in the following general equations, the points J and J' will be regarded as coincident; and the entire expansion line IH will be treated as of one form, or as characterized by one value of the exponent x in Eq. (1).

Area of the Indicator Cards; and General Equations.

An expression for the area of, or work represented by an indicator card like $FGKL$, Fig. 8, for one pound of steam in the usual notation is

$$p_1v_1 - \int pdv \tag{a}$$

where $p_1 = FD$, is the specific pressure of the steam, or absolute pressure per unit surface; usually pounds per square foot: $v_1 = FL$ the specific volume, or volume per unit weight; usually cubic feet per pound; and where p is the varying pressure under the curve GK. The first term of (a) gives the whole area $FDCL$, while the second term gives the area $GDCK$, the difference expressed being the area proposed. A similar expression answers for $IQSH$, except for the interchanging of terms, viz.:

$$\int pdv - p_3v_2. \tag{b}$$

These are for one pound, and not for the actual volumes V_1 and V_2. Hence the areas in (a) and (b) are simply *like* those of Fig. 8, but not equal to them.

But in the present case it will probably be most convenient

to apply our reasoning to the actual volumes V_1, V_2, and V' of the high cylinder, low cylinder, and receiver respectively.

For the present convenience let A = the area of the high-pressure piston, and l the length of its stroke. Then

$$V_1 = Al, \tag{3}$$

or multiplying through by P.

$$P_1^1 V_1 = P_1 Al = \text{actual area } FDCL. \tag{4}$$

Similarly below the expansion line GK.

$$\int_0^l PA\,dx = \text{actual area } GDCK, \tag{5}$$

or

$$= \int_{L_1}^{L_2} PA\,dx, \tag{5}$$

if L_1 = length AD and L_2 = length AC. The pressure P is here variable, but according to (1) and (2) the zero of volumes for GK being at A, Fig. 8.

$$\frac{P}{P_g} = \left(\frac{L_1}{x}\right)^a = \left(\frac{V' + V_2}{V}\right)^a \tag{$5\tfrac{1}{2}$}$$

Hence (5) becomes

$$\text{Area } GDCK = AP_g L_1^a \int_{L_1}^{L_2} \frac{dx}{x^a}$$

$$= AP_g L_1^a \frac{1}{1-a}\left(L_2^{1-a} - L_1^{1-a}\right);$$

or, since $L_2 = L_1 + l$.

$$GDCK = AP_g L_1^a \frac{1}{1-a}\left\{(L_1 + l)^{1-a} - L_1^{1-a}\right\}$$

$$= AP_g L_1 \frac{1}{a-1}\left\{1 - \left(\frac{L_1}{L_1 + l}\right)^{a-1}\right\}$$

$$= P_g \frac{V_2 + V'}{a-1}\left\{1 - \frac{1}{\left(1 + \frac{V_1}{V_2 + V'}\right)^{a-1}}\right\} \tag{6}$$

the last transformation depending on the relations $Al = V_1$ and $\frac{l}{L} \; \frac{V_1}{V_2 + V'}$.

This equation might be used in its present form for all cases except when $x = 1$, in Eq. (1), an assumption which it is desirable to make eventually. But for $x = 1$ (6) becomes indeterminate in the form now given. This difficulty is avoided, however, and in some respects with greater convenience, by developing $(L_1 + l)^{1-a}$ into a series by the binomal theorem, whence we obtain

$$GDCK = AP_g l \left\{ 1 - \frac{a}{2}\frac{l}{L_1} + \frac{a(a+1)}{2.3}\frac{l^2}{L_1^2} - \&c. \right\} \qquad \text{(c)}$$

$$= P_g V_1 \left\{ 1 - \frac{a}{2}\frac{V_1}{V_2 + V'} + \frac{a(a+1)}{2.3}\left(\frac{V_1}{V_2 + V'}\right)^2 - \&c. \right\}$$

$$= P_g V_1 M \qquad (7)$$

where for brevity we put M in place of the series, or where

$$M = 1 - \frac{a}{2}\frac{V_1}{V_2 + V'} + \frac{a(a+1)}{2.3}\left(\frac{V_1}{V_2 + V'}\right)^2 - \frac{a(a+1)(a+2)}{2.3.4}\left(\frac{V_1}{V_2 + V'}\right)^3 + \&c. \qquad \text{(I)}$$

In the denominators, $2.3 = 6$, and $2.3.4 = 24$, &c.

For the particular case $a = 1$, the integral becomes, for the small cylinder

$$\left.\begin{aligned} (GDCK)_{a=1} &= AP_g L_1 \, hyp. \, log. \left(1 + \frac{l}{L_1}\right) \\ &= P_g (V_2 + V') hyp. log. \left(1 + \frac{V_1}{V_2 + V'}\right) \end{aligned}\right\} (8)$$

In these equations P_g is the absolute pressure $DG, = EI$.

Similarly for the area $IEDH$, taking the point A, Fig. 8, as the zero of volumes, and putting

$$Al' = V_2 \text{ and } \frac{l'}{L'_1} = \frac{ED}{AE} = \frac{V_2}{V'},$$

and substituting them for Al and $\frac{l}{L_1}$ in the equation preceding (6), gives for the large cylinder the area

$$IEDH = P_g \frac{V'}{a-1}\left\{ 1 - \frac{1}{\left(1 + \frac{V_2}{V'}\right)^{a-1}} \right\} \qquad (8\tfrac{1}{2})$$

or, by the series in equation (c)

$$IEDH = P_g V_2 \left\{ 1 - \frac{a}{2}\frac{V_2}{V'} + \frac{a(a+1)}{6}\left(\frac{V_2}{V'}\right)^2 - \frac{a(a+1)(a+2)}{24}\left(\frac{V_2}{V'}\right)^3 + \&c., \right\}$$

$$= P_g V_2 N, \tag{9}$$

where for brevity we put N in place of the series, or where

$$N = 1 - \frac{a}{2}\frac{V_2}{V'} + \frac{a(a+1)}{2.3}\left(\frac{V_2}{V'}\right) - \frac{a(a+1)(a+2)}{2.3.4}\left(\frac{V_2}{V'}\right)^3 + \&c. \tag{II}$$

For $a = 1$, we have

$$(IEDH)_{a=1} = P_g V' \, hyp. \, log. \left(1 + \frac{V_2}{V'}\right). \tag{10}$$

Now the work done in the high-pressure cylinder, per stroke, is

$$P_1 V_1 - GDCK. \tag{11}$$

Also in the low-pressure cylinder it is

$$IEDH - P_3 V_2. \tag{12}$$

Hence, when the engine is working in continuity under the first valve movement of Fig. 7, and giving the diagram of Fig. 8, then, for one stroke of each piston in regular order of continuity, the same being the half of a complete cycle of operations detailed in Fig. 7, or, for each high-pressure cylinder full of steam, the work done will be the sum of (11) and (12); or, the effective work per stroke of both cylinders is $U = (P_1 V_1 - GDCK) + (IEDH - P_3 V_2)$

$$= P_1 V_1 - P_g V_1 M - P_3 V_2 + P_g V_2 N$$

$$= P_1 V_1 \left\{ 1 + \frac{P_g}{P_1}\left(\frac{V_2}{V_1} N - M\right) - \frac{P_3 V_2}{P_1 V_1} \right\} \tag{13}$$

and for $a = 1$

$$U' = P_1 V_1 \left\{ \begin{array}{l} 1 - \dfrac{P_g}{P_1}\dfrac{V_2 + V'}{V_1} hyp. \, log. \left(1 + \dfrac{V_1}{V_2 + V'}\right) \\ - \dfrac{P_3 V_2}{P_1 V_1} + \dfrac{P_g V'}{P_1 V_1} hyp. \, log. \left(1 + \dfrac{V_2}{V'}\right) \end{array} \right\} \tag{14}$$

The work performed by the engine for a complete cycle of operations, including two strokes of each cylinder, as already

explained, will evidently be equal to twice the work given by (13) or (14).

In attempting to apply either (13) or (14), everything is seen to be in known terms except P_g. This is the absolute back pressure in the high-pressure cylinder at the termination of its stroke, it is the absolute forward pressure in the low-pressure cylinder at the beginning of its stroke, and also it is the pressure at the same time in the receiver. Fig. 8 shows that this depends on many things, and that it is in no case, in itself, arbitrary, but that, in an actual engine, it is self-adjusting according to pressure of admission, dimensions of cylinders and receiver, mode of valve action, and laws of expansion.

To express P_g in convenient terms, we may write from Fig. 8 and by aid of (1) and (2), regarding J and J' as coincident,

$$\frac{P_1}{P_j} = \left(\frac{JK}{FL}\right)^n = \left(\frac{JK}{V_1}\right)^n.$$

Also,

$$\frac{P_1}{P_j} = \frac{P_g}{P_k} = \frac{P_g}{P_j} = \left(\frac{AC}{AD}\right)^a = \left(\frac{V_1 + V_2 + V'}{V_2 + V'}\right)^a = \left(1 + \frac{V_1}{V_2 + V'}\right)^a$$

Again, from the fact that the intercepts on horizontal lines lying between two curves constructed from (1) with one value for x and different values of $P_1 V_1$, are proportional to the abscissas to the intersection points of the horizontal lines with either curve, we may write

$$\frac{JK}{GI} = \frac{JK}{V_2} = \frac{AC}{AD} = \frac{V_1 + V_2 + V'}{V_2 + V'} = 1 + \frac{V_1}{V_2 + V'}.$$

Eliminating JK and combining, we get

$$\frac{P_g}{P_j} \cdot \frac{P_j}{P_1} = \frac{P_g}{P_1} = \left(1 + \frac{V_1}{V_2 + V'}\right)^a \cdot \left(\frac{V_1}{V_2}\right)^n \cdot \left(1 + \frac{V_1}{V_2 + V'}\right)^{-n}$$

$$= \left(\frac{V_1}{V_2}\right)^n \cdot \left(1 + \frac{V_1}{V_2 + V'}\right)^{a-n} \qquad (15)$$

Eliminating $\frac{P_g}{P_1}$ from (13) and (14) by aid of (15), we find for the work of the half cycle, or for one stroke each of the two cylinders in continuity,

$$U = P_1 V_1 \left\{ 1 + \left(\frac{V_1}{V_2}\right)^n \cdot \left(1 + \frac{V_1}{V_2 + V'}\right)^{a-n} \left(\frac{V_2}{V_1} N - M\right) - \frac{P_3 V_2}{P_1 V_1} \right\} \qquad (16)$$

and for the hyperbolic expansion where a and $n = 1$, we have

$$U' = P_1 v_1 \left\{ \begin{array}{l} 1 - \dfrac{V_2 + V'}{V_2} \, hyp. \, log. \left(1 + \dfrac{V_1}{V_2 + V'}\right) \\ - \dfrac{P_3 V_2}{P_1 V_1} + \dfrac{V'}{V_2} \, hyp. \, log. \left(1 + \dfrac{V_2}{V'}\right) \end{array} \right\}, \quad (17)$$

all quantities being in known terms. If $a = n$, the term $\left(1 + \dfrac{V_1}{V_2 + V'}\right)^n$ drops from (16).

If $V' = \infty$, and a and n as in (16), we get

$$U'' = P_1 V_1 \left\{ 1 - \left(\frac{V_1}{V_2}\right). + \left(\frac{V_1}{V_2}\right)^{n-1} - \frac{P_3 V_2}{P_1 V_1} \right\} \quad (18)$$

If $V^1 = \infty$, and a and $n = 1$, we get

$$U''' = P_1 V_1 \left(2 - \frac{V_1}{V_2} - \frac{P_3 V_2}{P_1 V_1}\right) \quad (19)$$

Two additional expressions for the work may also be written out readily, viz.:

For (16) with $n = 1$

$U^{\text{iv}} =$ (20)

and for (16) with $a = 1$

$U^{\text{v}} =$ (21)

In these expressions,

P_1 = absolute pressure of admission, lbs. per square foot = 144 ($p_1' + 14.7$), for p_1' = lbs. per square inch of boiler pressure.

P_3 = absolute back pressure to low-pressure cylinder lbs. per square foot of the atmosphere for exhausting into air, or of the condenser for condensing engines.

V_1 = volume of high-pressure cylinder in cubic feet.

V_2 = volume of low-pressure cylinder in cubic feet.

V' = volume of receiver and connecting pipes in cubic feet.

M and N being given by equations (I) and (II).

These equations are useful in calculating the amount of work that can be done by an engine, or in calculations for duty.

In practice any one of these equations can be used according to accuracy required, (16) being necessary for the greatest degree of exactness. It is seen, however, by (2) and the accom-

panying table that a much wider departure from truth results when $a = 1$ than when $n = 1$. When the steam is very wet the actual value of a will be much nearer unity than for dry steam. In such case some value of m should be used in place of a. Fig. 8, also, will indicate in some degree to what extent, in any practical case, we jeopardize the result by taking V' infinite in the calculations.

Pressure at Different Points of Steam Action.

It is often desirable to know the pressure at different points of the steam action in the engine. To this end we have (15) for the terminal pressure, p_g, in the high cylinder, and initial pressure in the low cylinder. This shows that if $a = n$ it matters not with p_g whether $V' = \infty$ or not. From this it appears that for $a = n$ the smaller we make V' the greater is the proportion of work done by the small and less by the large cylinder.

For the initial and final pressures in the low-pressure cylinder we have the relation

$$\frac{P_g}{P_2} = \left(\frac{V_2 + V'}{V'}\right)^a = \left(1 + \frac{V_2}{V'}\right)^a \tag{22}$$

combining with (15)

$$\frac{P_2}{P_1} = \left(\frac{V'}{V_2 + V'}\right)^a \cdot \left(\frac{V_1}{V_2}\right)^n \cdot \left(1 + \frac{V_1}{V_2 + V'}\right)^{a-n} \tag{23}$$

The 4th equation preceding (15), combined with the 2d, gives

$$\frac{P_1}{P_k} = \frac{P_1}{P_j} = \left(\frac{V_2}{V'}\right)^n \cdot \left(1 + \frac{V_1}{V_2 + V'}\right)^n \tag{24}$$

These equations show that for $V' = \infty$ we have

$$\frac{P_g \text{ or } P_j \text{ or } P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^n \tag{24$\frac{1}{2}$}$$

which is the constant pressure of the infinite receiver, and toward which this pressure approximates as V' is made large.

The varying pressure for the stroke of either cylinder may be obtained by aid of equation ($5\frac{1}{2}$).

Equation (15) shows that if $a = n$, as it will very nearly for wet steam, the pressure at G or I, $= P_g$, will be entirely inde-

pendent of V' whether infinite or finite. In this case the pressure P_g is what might be termed the pivotal pressure, since it remains fixed while all other pressures, except P_1 and P_3, vary with V'. The effects of this on the diagram are that the lines GK, or IH, swing around the points G and I as pivots, becoming flatter as V' is enlarged, or steeper as it is diminished. Hence as V' is enlarged, the work produced in V_1 decreases, while in V_2 it increases. Considering these variations, a look at diagram, Fig. 8, shows that the efficiency of this engine increases with V', and is a maximum when V' is infinite.

When $V' = 0$, V_2 does no work, and the engine does worse than a non compound, but equals it when $IQSH = GSS'K$.

Relative Areas of Indicator Cards.

It is also desirable to know the relation between the work developed in the high-pressure cylinder and the low. From the expressions (13) and (15) above given, we readily find

$$\frac{Wk.H.\text{-}Cyl.}{Wk.L.\text{-}Cyl.} = R = \frac{1 - M\left(\frac{V_1}{V_2}\right)^{n} \cdot \left(1 + \frac{V_1}{V_2 + V'}\right)^{a-n}}{N\frac{V_2}{V_1}\left(\frac{V_1}{V_2}\right)^{n} \cdot \left(1 + \frac{V_1}{V_2 + V^1}\right)^{a-n} - \frac{P_3 V_2}{P_1 V_1}}. \tag{25}$$

For the hyperbolic expansion this ratio is

$$R' = \frac{1 - \frac{V_2 + V'}{V_2}\, hyp.\, log.\left(1 + \frac{V_1}{V_2 + V'}\right)}{\frac{V_1}{V_2}\, hyp.\, log.\left(1 + \left(\frac{V_2}{V'}\right) - \frac{P_3 V_2}{P_1 V_1}\right.}. \tag{26}$$

If $V' = \propto$, and a and n are as in (25)

$$R'' = \frac{1 - \left(\frac{V_1}{V_2}\right)^{n}}{\left(\frac{V_1}{V_2}\right)^{n-1} - \frac{P_3 V_2}{P_1 V_1}}. \tag{27}$$

If $V_1 = \propto$, and a and $n = 1$

$$R''' = \frac{1 - \frac{V_1}{V_2}}{1 - \frac{P_3 V_2}{P_1 V_1}}. \tag{28}$$

Heat for Producing Steam.

The heat required to produce the steam used at a stroke of the high-pressure cylinder will be the total heat of evaporation from the temperature of feed water, and at the temperature of boiler pressure.

Let V_1 = the volume of steam required per stroke of high cylinder in cubic feet.

D_1 = the weight per cubic foot of the steam as supplied to the engine.

H_1 = the dynamical value of the total heat of evaporation per pound from 32° F., at the temperature of boiler pressure steam; that is, the heat to raise the temperature of the water from 32° F. to the temperature of the steam in the boiler, added to the latent heat of evaporation at the latter temperature. (Convenient values are given for this in the tables of *Rankine's Steam Engine*).

t_f = the actual temperature, Fahr., of the feed water.

J = Joule's equivalent, = 772 ft.-lbs.

Then the total heat consumed per high-pressure cylinder full of steam in dynamical value, or ft.-lb. units, is

$$H = V_1 D_1 (H_1 - J(t_f - 32°)). \tag{29}$$

Efficiency of the Engine.

The efficiency of the engine is obtained by dividing the ft.-lbs. of work developed by the engine for each high-pressure cylinder full of steam, by the dynamical value of the heat required to produce that steam; that is, the

$$\text{Efficiency} = \frac{U}{H}. \tag{30}$$

Maximum Efficiency.

In the compound engine now under consideration, the efficiency will, it appears, vary with changes in the relative sizes of the cylinders. For instance, if both cylinders are of equal size and the receiver is very large, the first cylinder does almost no work, because the receiver must now receive the same volume of steam as it discharges, per stroke; and there will be no expansion between the cylinders. Hence the engine now works without expansion, and with consequent

low efficiency. On the other hand, if there be a very great disparity of cylinder sizes, the low-pressure cylinder may exhaust the steam so rapidly from the receiver as to carry its pressure as low or even lower than the back pressure. At the limit of equal back and receiver pressure, no work will be done by the low-pressure cylinder, and the high-pressure cylinder exhausts, in effect, into the back pressure direct. Here again we have no working expansion, and a correspondingly low efficiency. It is evident that between these limits there exists a relation of sizes which will give a maximum of efficiency.

To determine this relation, assume a fixed volume of V_1 and of V', while V_2 is made to vary. In this way the quantity of steam used per stroke is invariable, so that the denominator of (30) is constant.

Hence, for the maximum of (30), we have only to examine the numerator, or to examine (16), (17), or (18), etc., according to contemplated accuracy. This could be done by working out several values from which to construct a curve, the maximum ordinate of which corresponds to the maximum sought. This plan is probably advisable for (16) and (17).

If we place the differential coefficient of U'' with respect to V_2 from (18) equal zero, we get after reduction, for the case $V' = \infty$,

$$\frac{P_3}{P_1} = \left(\frac{V_1}{V_2}\right)^n \left(n \left(\frac{V_1}{V_2}\right) n - 1)\right), \tag{31}$$

an equation which is irresolvable for the desired quantity, viz., $\frac{V_1}{V_2}$. But for a series of assumed values of $\frac{V_1}{V_2}$ the corresponding values of $\frac{P_3}{P_1}$ may be computed and tabulated. A sufficiently extended table would answer all cases, requiring conditions for the maximum efficiency.

If $n = 1$, then (31) reduces to

$$\frac{P_3}{P_1} = \left(\frac{V_1}{V_2}\right)^2. \tag{32}$$

Eliminating $\frac{P_3}{P_1}$ between (31) and (18) we find the maximum of U'', or for the infinite receiver, with n as in (18);

$$U''_{\text{max.}} = P_1 V_1 \left\{ 1 - \left(\frac{V_1}{V_2} \right)^n \left(1 + n - n \frac{V_2}{V_1} \right) \right\}. \qquad (32\tfrac{1}{2})$$

From this, for $n = 1$, or for (32) in 19, we obtain for $V' = \alpha$ and $n = 1$ the maximum of U'''.

$$U'''_{\text{max.}} = 2P_1 V_1 \left(1 - \frac{V_1}{V_2} \right)$$

$$= 2P_1 V_1 \left(1 - \frac{P_1}{P_3} \right)^{\frac{1}{2}}. \qquad (33)$$

Conditions for Equal Work of Cylinders.

In practice it is probably desirable that the cylinders do equal work, particularly so in the Worthington pumping engine, where the especially important point is made of destroying the "water hammer" in connection with the water-valve action; and of maintaining perfect uniformity of pressure and motion of the travelling water column.

To obtain an equation which shall express the conditions necessary for such equality of work of the two cylinders, we have only to place the numerator and denominator of (25) equal to each other, which becomes

$$\frac{P_3 V_2}{P_1 V_1} = \left(M + N \frac{V_2}{V_1} \right) \left(\frac{V_1}{V_2} \right)^n \left(1 + \frac{V_1}{V_2 + V'} \right)^{a-n} - 1. \qquad (34)$$

In using this equation it will be necessary to assume a set of volumes and find the ratio $\frac{P_3}{P_1}$, a satisfactory value for which may require several trials.

If $V' = \alpha$ (34) reduces to

$$\frac{P_3 V_2}{P_1 V_1} = \left(1 + \frac{V_2}{V_1} \right) \left(\frac{V_1}{V_2} \right)^n - 1. \qquad (35)$$

If $n = 1$, also,

$$\frac{P_3}{P_1} = \left(\frac{V_1}{V_2} \right)^2. \qquad (36)$$

This last is the same as (32), which gives the condition for a maximum efficiency. Hence, for the case that the receiver has an infinite volume, and $n = 1$, the engine works with its maximum efficiency when the cylinders do equal portions of the work. When the receiver is eight or ten times as large as the

low-pressure cylinder, this engine, with its valves working as stated, is not far from working with its maximum efficiency.

II. Solution for the Second Valve Movement of Fig. 7.

The complete diagram of steam action in continuity for this case is shown in Fig. 9. The notation is as before, AC being the volume of the three parts V_1, V_2, and V'.

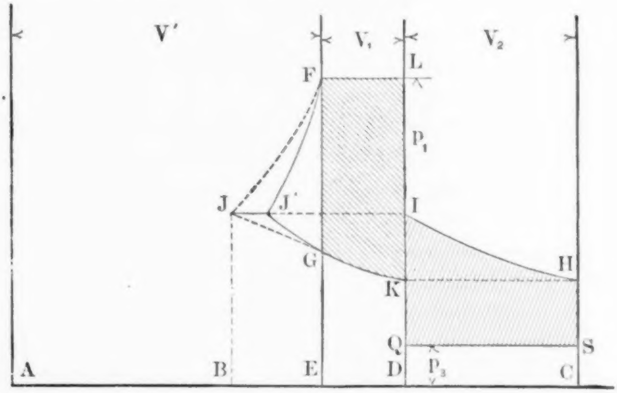


Fig. 9.

The piston motions are the same here as shown in Fig. 7, and, indeed, the same as in Case I. The sole cause for the difference in diagrams is in the valve movement, as indicated in the second part of Fig. 7.

The Complete Diagram and Indicator Cards.

When the H-piston has completed its forward stroke, all under the full boiler pressure P_1, the boiler steam is to be immediately cut off, and to be exhausted into the receiver. The resulting pressure is $BJ = DI = P_J$. The valve remains open, and H-piston stands, while the L-piston makes its stroke. The latter starts while the volume of active steam is that in the receiver and H-cylinder together, and equals $AD = V_1 + V'$. Hence, the expansion line for this stroke is IH, drawn with the point A for the zero of volumes. Immediately on completing the stroke, the admission valve from the receiver is closed, retaining the steam in the L-cylinder while its piston stands. Consequently the H-piston starts its stroke with a back pressure $DK = CH$ of the terminal stroke of the

L-piston. The volume subject to this back pressure is AD at the start of the H-piston, but during this stroke it is compressed to AE, giving the compression line KG. Then the valve immediately opens, as explained, to release the high steam which made this stroke. This steam expands against that in the receiver, which was compressed on the back stroke, giving the actual compression curve GJ' and expansion curve FJ'; the pressures EG and EF meeting in a common pressure at J'. Then the L-cylinder starts again on the curve HI, while the H-piston stands, and so on in repetition.

The valve movement is thus seen to be peculiar. Here, instead of the valves of one cylinder all moving simultaneously, and so with the other cylinder, they move in alternation. This will complicate the valve-gear somewhat.

It is to be observed that by this arrangement, the high steam is at once released from the H-cylinder on completion of stroke, so that it is available to the L-cylinder. Also, in the L-cylinder, the steam is retained while that piston stands, instead of being at once exhausted; the object being to keep this cylinder hot as possible.

Nature of the Expansion and Compression Lines.

The point of zero of volumes for the curves HI and KGJ' or J, is A, Fig. 9, while for FJ, or FJ', it is D. The back pressure line of the L-cylinder is QS. The duplex point JJ' is due to the same causes here as in the first solution. In the union of volumes, the resulting pressure BJ or J' is regarded as very nearly the same as that found by drawing the two isodynamic lines GJ and FJ; isodynamic because of the absence of external work in the act of combining of pressures. But in the compression from G, work is done on the steam in the receiver, by the expanding steam from the H-cylinder, so that instead of the isodynamic GJ we will actually have the adiabatic GJ', and the expansion curve of partial work FJ'. Heating accompanies the adiabatic compression GJ', while in the expansion FJ' there will be cooling. In this way the different temperatures of F and G will approach a common point, but will probably not reach it until the end of the full commingling which follows the common pressure. Observing that $J'I$ stands for the expanded volume of the high steam, the temperature of which is higher to some slight extent than that

in the receiver as compressed to J'; it appears that after the full commingling has taken place, and the temperatures become common, the point J' will have moved slightly toward I. This is on the supposition that J' is regarded as the point which divides the united volumes AD in such proportions that $J'I$ contains exactly the weight which was delivered by the expansion of FL.

Dryness of the Expanding Steam.

Respecting the dryness of the steam in the receiver, it appears that if FJ and GJ represent the equivalent of the actual process of combining, then the result at J will be a slight superheating. Now as the united volume expands adiabatically from I to H, there will probably be formed an appreciable amount of fog as supersaturating moisture. This will be exactly re-evaporated in the exact counter operation KJ', unless a portion of that moisture is precipitated to the bottom of the receiver as water, to collect into pools. In such event, it will not be so readily re-evaporated, and a considerable quantity of water may thus collect to be drawn off occasionally by a cock.

Insignificance of JJ'.

Similar reasoning may be applied to the discrepancy JJ', as was done in the first solution, to show that it is small. It will, therefore, be disregarded in the following analysis, KGJ' and IH being regarded as adiabatic, and FJ' as isodynamic.

Area of Indicator Cards and General Equations.

The expressions (a) and (b) are suitable for the present case. Take

$$V_1 = Al$$
$$L_1 = \text{length } AE$$
$$L_2 = \text{length } AD$$

Then

$$P_1V_1 = P_1Al = \text{actual area } FEDL.$$
$$L_2 = L_1 + l$$
$$\frac{l}{L_2} = \frac{V_1}{V_1 + V'}$$
$$\frac{P}{P_k} = \left(\frac{L_2}{x}\right)^n \tag{36½}$$

$$\text{Area } GEDK = AP_k L_2^a \int_{L_1}^{L_2} \frac{dx}{x^a}$$

$$= \frac{AP_k L_2^a}{1-a} \left\{ L_2^{1-a} - L_1^{1-a} \right\}$$

$$= \frac{AP_k L_2^a}{1-a} \left\{ L_2^{1-a} - (L_2 - l)^{1-a} \right\}$$

$$= P_k \frac{V_1 + V'}{a-1} \left\{ \left(1 + \frac{V_1}{V'}\right)^{a-1} - 1 \right\} \qquad (37)$$

The corresponding equation for the L-cylinder is obtained from (37) by putting $V_1 + V_2 + V'$, for $V_1 + V'$, and also $\frac{V_2}{V_1 + V'}$, for $\frac{V_1}{V'}$.

These equations become indeterminate when $a = 1$. To provide for this case expand $(L_2 - l)^{1-a}$ by the binomial formula, and the equation preceding (37) becomes

$$GEDK = AP_k l \left\{ 1 + \frac{a}{2} \frac{l}{L_2} + \frac{a(a+1)}{2.3} \frac{l^2}{L_2^2} + \text{\&c.,} \right\} \qquad (d)$$

$$= P_k V_1 \left\{ 1 + \frac{a}{2} \frac{V_1}{V_1 + V'} + \frac{a(a+1)}{2.3} \left(\frac{V_1}{V_1 + V'} \right)^2 + \text{\&c.} \right\}$$

$$= P_k V_1 Q \qquad (38)$$

where for brevity we put for the series

$$Q = 1 + \frac{a}{2} \frac{V_1}{V_1 + V'} + \frac{a(a+1)}{2.3} \left(\frac{V_1}{V_1 + V'} \right)^2 +$$

$$\frac{a(a+1)(a+2)}{2.3.4} \left(\frac{V_1}{V_1 + V'} \right)^3 + \text{\&c.} \qquad \text{(III)}$$

For the particular case that $a = 1$, the above integral becomes

$$(GEDK)_{a=1} = AP_k L_2 \, hyp. \, log. \frac{L_2}{L_1} \qquad (e)$$

$$P_k (V_1 + V') \, hyp. \, log. \left(1 + \frac{V_1}{V'}\right) \qquad (39)$$

in all of which $P_k =$ the pressure $DK = CH$.

In a similar way we find for the area $IDCH$ of the large cylinder, by using equation (d) and assuming

$$Al = V_2 \text{ and } \frac{l}{L_2} = \frac{DC}{AC} = \frac{V_2}{V_1 + V_2 + V'}$$

$$IDCH = P_k V_2 \left\{ 1 + \frac{a}{2} \frac{V_2}{V_1 + V_2 + V'} + \right.$$

$$\left. \frac{a(a+1)}{2.3} \left(\frac{V_2}{V_1 + V_2 + V'} \right)^2 + \&c. \right\}$$

$$= P_k V_2 S \tag{40}$$

where for brevity and convenience we put

$$S = 1 + \frac{a}{2} \frac{V_2}{V_1 + V_2 + V'} + \frac{a(a+1)}{2.3} \left(\frac{V_2}{V_1 + V_2 + V'} \right)^2 +$$

$$\frac{a(a+1)(a+2)}{2.3.4} \left(\frac{V_2}{V_1 + V_2 + V'} \right)^3 + \&c. \tag{IV}$$

For the particular case that $a = 1$, (e) becomes

$$(IDCH)_{a=1} = P_k (V_1 + V_2 + V') \, hyp. log. \left(1 + \frac{V_2}{V_1 + V'} \right) \tag{41}$$

Now the work done in the high-pressure cylinder will be

$$FGKL = P_1 V_1 - GEDK, \tag{42}$$

and in the low-pressure cylinder it will be

$$IQSH = IDCH - P_3 V_2. \tag{43}$$

For the engine working in continuity the work developed during a half cycle, or for one stroke of each cylinder, or by each high-pressure cylinder full of steam, will be the sum of (42) and (43), or

$$U = (P_1 V_1 - GEDK) + (IDCH - P_3 V_2)$$

$$= P_1 V_1 - P_k V_1 Q - P_3 V_2 + P_k V_2 S$$

$$= P_1 V_1 \left\{ 1 + \frac{P_k}{P_1} \left(\frac{V_2}{V_1} S - Q \right) - \frac{P_3 V_2}{P_1 V_1} \right\} \tag{44}$$

and for $a = 1$

$$U' = P_1 V_1 \left\{ \begin{array}{l} 1 - \frac{P_k}{P_1}\left(1 + \frac{V'}{V_1}\right) hyp.\ log. \left(1 + \frac{V_1}{V'}\right) \\ - \frac{P_3 V_2}{P_1 V_1} + \frac{P_k}{P_1}\left(1 + \frac{V_2 + V'}{V_1}\ hyp.\ log. \right. \\ \qquad \left. \left(1 + \frac{V_2}{V_1 + V'}\right)\right) \end{array} \right\} \quad (45)$$

But in these equations p_k is as yet unknown. Regarding J and J' as coincident on the adiabatic KG produced, then from the proportionality of horizontal intercepts between adiabatics, we may write

$$\frac{HK}{IJ} = \frac{AC}{AD} = \frac{V_2 + V_1 + V'}{V_1 + V'} = 1 + \frac{V_2}{V_1 + V'} = \frac{V_2}{IJ}$$

$$= \frac{V_2}{IJ} = \left(\frac{P_1}{P_k}\right)^{\frac{1}{n}} = 1 + \frac{V_2}{V_1 + V'}.$$

Also,

$$\frac{P_1}{P_1} = \left(\frac{V_1}{IJ}\right)^n = \left(\frac{V_1}{V_2}\right)^n \left(1 + \frac{V_2}{V_1 + V'}\right)^n \quad (46)$$

Hence

$$\frac{P_1 P_k}{P_1 P_1} = \left(\frac{V_1}{V_2}\right)^n \left(1 + \frac{V_2}{V_1 + V'}\right)^{n-a} = \frac{P_k}{P_1} = \frac{P_2}{P_1} \quad (47)$$

This introduced in (44) gives in known terms the amount of work per high-pressure cylinder full of steam.

$$U = P_1 V_1 \left\{ 1 + \left(\frac{V_2}{V_1} S - Q\right) \left(\frac{V_1}{V_2}\right)^n \cdot \left(1 + \frac{V_2}{V_1 + V'}\right)^{n-a} - \frac{P_3 V_2}{P_1 P_1} \right\} \quad (48)$$

If $a = n$, the term $\left(1 + \frac{V_2}{V_1 + V'}\right)$ drops out. For a and n $= 1$,

$$U = P_1 V_1 \left\{ \begin{array}{l} 1 - \frac{V_1 + V'}{V_2} hyp.\ log. \left(1 + \frac{V_1}{V'}\right) \\ - \frac{P_3 V_2}{P_1 V_1} + \left(1 + \frac{V_1 + V'}{V_2} hyp.\ log. \left(1 + \frac{V_2}{V_1 + V'}\right)\right) \end{array} \right\} \quad (49)$$

If $V' = \infty$, and a and n as in (48), we get

$$U'' = P_1 V_1 \left\{ 1 - \left(\frac{V_1}{V_2}\right)^n + \left(\frac{V_1}{V_2}\right)^{n-1} - \frac{P_3 V_2}{P_1 V_1} \right\} \quad (50) \text{ or } (18)$$

the same as (18).

If $V' = \infty$, and a and $n = 1$, we get

$$U''' = P_1 V_1 \left\{ 2 - \frac{V_1}{V_2} - \frac{P_3 V_2}{P_1 V_1} \right\} \qquad (51) \text{ or } (19)$$

the same as (19).

The notation is the same as stated following (21) for P_1, P_3, V_1, V_2, and V'. Q and S stand for the infinite series given in (III) and (IV).

One fact to be observed particularly, in comparing these equations with those for the I solution, is the perfect agreement of the expressions for the work U as soon as V' is made infinite. This is evidently as it should be, since for an infinite volume of receiver it would not matter whether the high pressure exhausted into it immediately on completion of its stroke, or whether the exhaust were stayed each time during the half stroke; because the pressure could not vary appreciably in the infinite receiver during this time. For the infinite receiver it is only essential that equal weights be received from the high cylinder, and delivered to the low cylinder per stroke, the strokes being regarded as the same per minute for one as for the other cylinder.

The coincidence of the expressions for work, for the case of an infinite receiver, is therefore expected; and the fact of coincidence corroborates the analysis.

These equations (48) to (51) serve in calculations for duty where the whole work done for a period is compared with the coal consumed. In selecting the equation for use, judgment must be exercised as to the degree of approximation necessary in the case, and as to the proper values of a and n. Wet steam will require different values than dry, the value of a for such case being more properly m, as found in table (2).

Pressure at Different Points of Steam Action.

To determine the pressure of the steam at different points of action in the engine, we observe first that for $V' = \infty$, the pressures at H, I, J, and K, Fig. 9, become one and the same; that is to say, the pressure in the receiver remains constant, and the indicator diagrams for the two cylinders are simple rectangles.

For the pressure at I or J see Eq. (46).

For the pressure at H or K see Eq. (47), where $P_k = P_2$.

These give the initial and terminal pressures in the low cylinder, and the initial back pressure in the high cylinder. The terminal back pressure in the high cylinder is $P_g = EG$, for which, by aid of Fig. 9, we may write

$$\frac{P_g}{P_k} = \left(\frac{V_1 + V'}{V'}\right)^a = \left(1 + \frac{V_1}{V'}\right)^a.$$

Combining with (47),

$$\frac{P_g}{P_k} \cdot \frac{P_k}{P_1} = \left(1 + \frac{V_1}{V'}\right)^a \left(\frac{V_1}{V_2}\right)^n \left(1 + \frac{V_2}{V_1 + V'}\right)^{n-a} = \frac{P_g}{P_1}. \quad (52)$$

If $V' = \infty$, these equations, as well as (46) and (47), reduce to

$$\frac{P_g \text{ or } P_1 \text{ or } P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^n \quad (53)$$

a common pressure, or a constant pressure of receiver, as above stated, for the case the receiver is infinite in volume. This equation also shows that n is the only exponent upon which the pressure of the infinite receiver depends. It also gives the pressure to which that of the receiver approaches as V' is made relatively very large.

The varying pressure at different points of stroke may be obtained by aid of ($36\frac{1}{2}$).

Equation (47) shows that if $a = n$, as it will nearly for wet steam, the pressure at H or K, $= P_2$, will be entirely independent of V' whether $V' = \infty$ or not. In this case the larger the receiver the greater will be the proportion of work done by the high cylinder, and the less by the low cylinder, as indicated by Fig. 9. The pressure P_2 is here the pivotal pressure.

It is a curious fact that for $a = n$, the so-called pivotal pressures, for both valve movements shown in Fig. 7, have one and the same value; as indicated by equations (15) and (47) for $a = n$. That is to say, for given initial pressures and ratio of cylinder volumes, the pressures of P_g of Fig. 8, and P_k of Fig. 9, are equal and constant, whatever the value of V'. Again, it is immaterial to this pressure whether $a = n$, or $V = \infty$; and it is given by ($24\frac{1}{2}$) or (53), another evidence that for the infinite receiver the mode of operation of valves is unimportant, whether according to 1st or 2d of Fig. 7.

The ratio of equations thus:

$$\frac{(23)}{(47)} > 1$$

shows that the second valve movement results in a greater ratio of expansion than the first when V' is not infinite.

Relative Areas of Indicator Cards.

To find the relation between the amounts of work developed by the high-pressure cylinder and the low, we may take their ratio thus:

$$R = \frac{1 - Q\left(\frac{V_1}{V_2}\right)^n \cdot \left(1 + \frac{V_2}{V_1 + V'}\right)^{n-a}}{S\frac{V_2}{V_1}\left(\frac{V_1}{V_2}\right)^n \left(1 + \frac{V_2}{V_1 + V'}\right)^{n-a} - \frac{P_3 V_2}{P_1 V_1}} \qquad (54)$$

For a and $n = 1$;

$$R' = \frac{1 - \frac{V_1 + V'}{V_2}\, hyp.\, log. \left(1 + \frac{V_1}{V'}\right)}{\left(1 + \frac{V_1 + V'}{V_2}\right) hyp.\, log. \left(1 + \frac{V_2}{V_1 + V'}\right) - \frac{P_3 V_2}{P_1 V_1}} \qquad (55)$$

If $V' = \infty$, and a and n as in (54),

$$R'' = \frac{1 - \left(\frac{V_1}{V_2}\right)^n}{\left(\frac{V_1}{V_2}\right)^{n-a} - \frac{P_3 V_2}{P_1 V_1}} \qquad (56)$$

If $V' = \infty$, and a and $n = 1$

$$R''' = \frac{1 - \frac{V_1}{V_2}}{1 - \frac{P_3 V_2}{P_1 V_1}} \qquad (57)$$

Equations (56) and (57) are seen to be identical with (27) and (28), which is evidently correct for the infinite receiver.

Heat for Steam Production.

The heat required for making the steam is evidently the same here as in the first form of engine, or as given in equation (29).

Efficiency.

Hence we have the

$$\text{Efficiency} = \frac{U}{H} \cdot \tag{58}$$

For steam under given conditions, the denominator, H, is constant. Then evidently U will vary with the relative dimensions of V_1, V_2, or V'; and also with the values of a and n. The maximum value is therefore desirable.

Maximum Efficiency.

The maximum of (48) or (49) may be found by the same process as indicated for (16) or (17). The maximum of (50) is the same as for (18), because the equations are identical. Hence for U'' the conditions for a maximum are obtained from (31); also (32) follows for $n = 1$. Hence the maximum values of U'' and U''' for the present case are found in equations ($32\frac{1}{2}$) and (33).

But it is a remarkable fact that the maximum efficiency of this engine is exactly equal to that of the Woolf engine, without receiver, shown in Fig. 13, below. That is to say, when $a = n = m$, equation (61) below is the maximum of (48). This can be proved by using for the expression of the work, the same as (48) obtained by aid of (37), and the corresponding one for the L-cylinder; also (47); and finally the relations

$$\frac{V_2}{V_1} = \frac{V_1 + V'}{V'} = \frac{V_1 + V_2 + V'}{V_1 + V'},$$

obtained from Fig. 9, on the supposition that V' is made so small that the compression line KG is so raised that it extends from K direct to F. This compression line then becomes a cushion line, such that on the return stroke of the H-piston, the remaining steam is compressed and forced into the receiver until at the end of the return stroke the boiler pressure is just restored at F.

The size of the receiver for this special case is $V' = \dfrac{V_1^2}{V_2 - V_1}$; also the isodynamic expansion now vanishes so that this maximum is general.

Conditions for Equal Work of Cylinders.

That the cylinders do equal work, the numerator and denominator of (51) must equal each other, which condition gives

$$\frac{P_3 V_2}{P_1 V_1} = \left(Q + S\frac{V_2}{V_1}\right)\left(\frac{V_1}{V_2}\right)^n\left(1 + \frac{V_2}{V_1 + V'}\right)^{n-n} - 1, \quad (59)$$

the solution of which may be proceeded with as suggested for (34).

If $V' = \infty$, this expression reduces to the same as (35), as it should; also to (36), for $n = 1$. This last is seen to be the same condition as for the maximum efficiency, for $V' = \infty$ and $n = 1$, as stated for the first engine, in which respect the engines agree.

The Infinitude of Possible Pump Movements.

In all the preceding cases the piston motion has been regarded as such that when one piston moves for making its complete stroke the other piston stands still at the end of its cylinder, and *vice versa*, as in the celebrated Worthington Pumping Engine. But compound pumping engines are in use in which we find the three parts, V_1, V_2, and V' as above, but with different piston and valve motions, as, for instance, in case of certain Cope & Maxwell pumping engines.

Respecting the possible variety of engines due to unlimited suppositions for piston motion, or valve motion, or both, it appears to be infinite. For almost any one of these, the diagrams corresponding with Fig. 8 or 9 become exceedingly difficult to delineate, except for the simple case $V' = \infty$. For instance, there might be the tarrying of the pistons, each for half or other fraction of its time; but with the relative period of strokes indifferent. The steam cylinders might be of equal volume, while one makes twice as many strokes as the other, and thus obtain expansion. This is admissible with or without tarrying of pistons. While the high piston tarries, its valve might open into the receiver at any point of time in the period of tarrying. And the low cylinder might close its valve from the receiver at any point in the tarrying of its piston. A comparatively simple case is that where the pistons do not tarry, and where the valves all work promptly on the termina-

tion of the strokes of their respective pistons. But here the periods of stroke of pistons might be in any given relation.

III. Strokes Co-initial and Co-terminal; without Tarrying.

To take an example of a simple case, let the pistons both make the same number of strokes per minute, and be so related that both begin and end their strokes together. For this case a little consideration will show that it matters not at which end of stroke one piston is, while the other starts at a particular end; because, for either one piston, the same changes occur at one end as at the other end of stroke. And let there be no tarrying, but both pistons moving continuously. For this, a little consideration will show that this engine may be rotative, with cranks at 180°, and one cylinder to each.

Complete Diagram and Indicator Cards.

Let Fig. 10 serve us for diagram of operations. The shaded areas are to be taken as the indicator diagrams; see footnote, p. 148. The volumes are as shown.

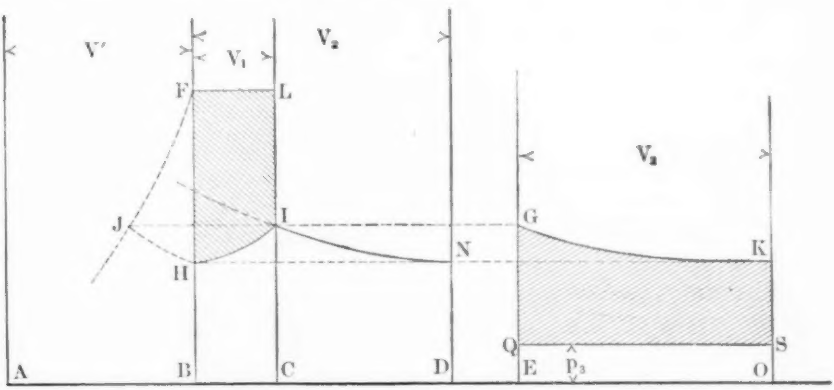


Fig. 10.

Now when the *H*-piston has terminated its stroke, let the back pressure from the receiver be *BH*, Fig. 10. As the valves of the *H* cylinder reverse, the exhaust raises the pressure by the commingling of the high steam *BF* with the receiver steam *BH*, with the resulting pressure as for the point *J*, equal *CI*. This new pressure is the initial back pressure for the *H*-pis-

ton, and the initial forward pressure for the L-piston for the next stroke. The volume of this steam includes that of the receiver and H-cylinder, or is equal $AC = V' + V_1$. The pistons now start and make their strokes together, the volume included increasing from AC to $AD = V' + V_2$, giving the expansion line IN drawn from A as the zero of volumes. Hence the pressure falls from CI to DN during the stroke of each piston, giving therefore the line IH for the underside of the H-cylinder indicator card; and GK for the top line for the L-cylinder card. This latter card is drawn to one side to avoid confusing the figure.

We will not stop to recount the complete analysis for this.

For any case in practice, if the pressures at I and N, or H are known, the diagrams could be laid out on a drawing-board, and the areas measured with a planimeter. In this, to construct GK or IH from IN, it is only necessary to divide CD, BC, and EO into a certain number of equal parts, and draw horizontal lines from the points of intersection with IN. The corresponding points of intersection on IH and GK will be points in the curves required. IN is to be drawn from A as the origin of volumes.

For pressures we have,

$$\frac{P_i}{P_n} = \left(\frac{V_2 + V'}{V_1 + V'}\right)^a$$

$$\frac{P_1}{P_i} = \left(\frac{IJ}{V_1}\right)^n$$

$$\frac{P_n}{P_i} = \left(\frac{IJ}{V_2}\right)^a$$

whence

$$\frac{CL}{CI} = \frac{P_1}{P_i} = \left(\frac{V_2}{V_1}\,\frac{V_1 + V'}{V_2 + V'}\right)^n$$

$$\frac{CL}{DN} = \frac{P_1}{P_n} = \left(\frac{V_2}{V_1}\right)^n \left(\frac{V_2 + V'}{V_1 + V'}\right)^{a-n}$$

by aid of which the diagram can be accurately constructed.

For an infinite receiver $V' = \infty$; and the equations for pressures reduce to

$$\frac{P_1}{P_i} = \frac{P_1}{P_n} = \left(\frac{V_2}{V_1}\right)^n \qquad (60)$$

which is the same as ($24\frac{1}{2}$) and (53) for this case of $V' = \infty$, which shows that, for the infinite volume of receiver, all these engines have the same efficiency. The same is true for $a = n$, making P_n the pivotal pressure.

The work performed by each high-pressure cylinder full of steam is readily obtained by aid of (37), and a comparison of Figs. 9, and 10. Thus we see that (37) gives the area *ICDN*, Fig. 10, if in (37) we change P_k to P_n; $V_1 + V'$ to $V_2 + V'$; and $\frac{V_1 + V'}{V'}$ to $\frac{V_2 + V'}{V_1 + V'}$; also, Fig. 10, the area $BHIND =$ area $EGKO$. Hence the work per *H*-cylinder full of steam is $BFLIND - P_3 V_2$, or

$$U = P_1 V_1 + P_n \frac{V_2 + V'}{a - 1}\left(\left(\frac{V_2 + V'}{V_1 + V'}\right)^{a-n} - 1\right) - P_3 V_2$$

and eliminating P_n

$$= P_1 V_1 \left\{1 + \left(\frac{V_1}{V_2}\right)^n \frac{V_2 + V'}{V_1(a-1)}\left(\left(\frac{V_2 + V'}{V_1 + V'}\right)^{a-1} - \right) - \frac{P_3 V_2}{P_1 V_1}\right\} \qquad \text{(f)}$$

If $V' = 0$ the receiver is dispensed with, and this case reduces to that of Fig. 13. The above, for $n = a$ then reduces to

$$U_1 = P_1 V_1 \left\{\frac{a}{a-1} - \frac{1}{a-1}\left(\frac{V_1}{V_2}\right)^{a-1} - \frac{P_3 V_2}{P_1 V_1}\right\} \qquad (59\tfrac{1}{2})$$

which is the same as (61) if a is changed to m, as it should be for the present supposition of no isodynamic expansion nor consequent superheating. The change in diagram, Fig. 10, where $V' = 0$, is in the raising of the point I up to L. The diagram then agrees with Fig. 15, below.

As the volume of the receiver is changed from zero to infinity, the point I, Fig. 10, falls from L to the horizontal through N; while the point N remains stationary. To find the point I on a drawing-board for any set of values of V_1, V_2 and V''; first find N by aid of (60), then draw the adiabatic NI with the proper exponent, and with A for the zero of volumes.

We thus arrive at the important conclusion that by increasing the size of the receiver we diminish the amount of work performed by the same weight of steam, and to the extent due to the corresponding lowering of the line NI.

In the volume V' of receiver must be included all the space

about the valves and of the communicating pipes between the cylinders, as well as that in a receiver proper. Thus the superheating chambers sometimes employed between the cylinders must be counted in.

The effect of superheating in the receiver is to change the pressures and not the volumes. Such superheating simply raises the lines *NI* and *HI*. If the steam is dry without a superheater, then with it these lines will be raised nearly in proportion to the elevation of the absolute temperature by superheating.

IV. Strokes Interfluent, without Tarrying.

As an example of a case not quite so simple, and to show the effect of interruption due to the exhaust into the receiver from the high cylinder while the low cylinder is making its

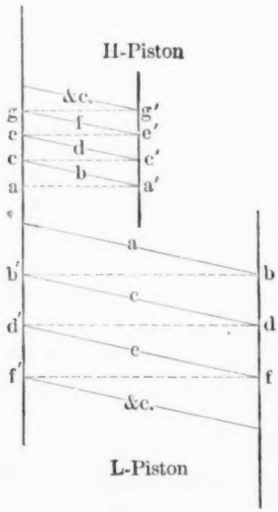


Fig. 11.

stroke, let the reversal of stroke for either piston be at the midstroke of the other. Then Fig. 11 may serve to indicate the relation between piston positions for continuity. The part *H* refers to the high cylinder, and *L* to the low. Now suppose *H* on the point of exhausting into the receiver, and let *a* represent the beginning and *a'* the end of this operation. This takes place at the midstroke, *a*, of the *L*-piston, as shown in

the L part of the diagram. As H exhausts, the increase of volume of receiver and connections will increase in the operation by an amount aa' on a proper scale. Now the H-piston travels from a' to b while the L-piston travels from a to b. Then the L-cylinder exhausts into the air or condenser, and its volume is cut off from the receiver to begin a new cylinder full. This volume cut off from the receiver is bb', as shown on the L part of the figure. This takes place at the midstroke b of the H-piston; see Fig. 11. And thus these operations continue, as can readily be traced from Fig. 11.

Now when a piston makes a half-stroke, the change of volume of the receiver and connections will not change by that amount alone, because two pistons are in action simultaneously, and the change of volume just referred to will be due to the combined movements of pistons, one of which (the H-) is compressing, and the other (the L-) is expanding this volume. We observe that the high piston *always* compresses, and the low expands this volume.

The letters a, b, c, d, etc., on Fig. 11, for any one letter denotes a single point of time, so that by referring to any single letter we can at once see the relative positions of both pistons. The stretches between a and a', c and c', etc., or b and b', d and d', etc., indicate shifting of action from end to end. Thus, when the exhaust is completed from one side of the H-piston, it immediately begins from the other side.

For the simultaneous positions, a, we see that the L-piston is at midstroke, while the H-piston is exhausting. Just before beginning the exhaust, a, the total volume in the receiver and connections is $V' + \frac{V_2}{2}$, and just after it is $V' + \frac{V_2}{2} + V_1$, as can easily be traced. For the point b, the H-piston is at midstroke, and the L-cylinder is on the point of exhausting and changing the volume from $V' + V_2 + \frac{V_1}{2}$ to $V' + \frac{V_1}{2}$, etc., etc. These changes of volume of receiver and connections are better shown in Fig. 12.

The Complete Diagram and Indicator Cards.

The shaded areas of Fig. 12 are the indicator cards for the cylinders. The volumes indicated show to which either card

belongs. All besides the shaded cards are construction lines used in obtaining the expansion lines and cards.

The lower part of the figure shows the variations in volume. $AB = V'$ is the volume of the receiver itself. At a we have

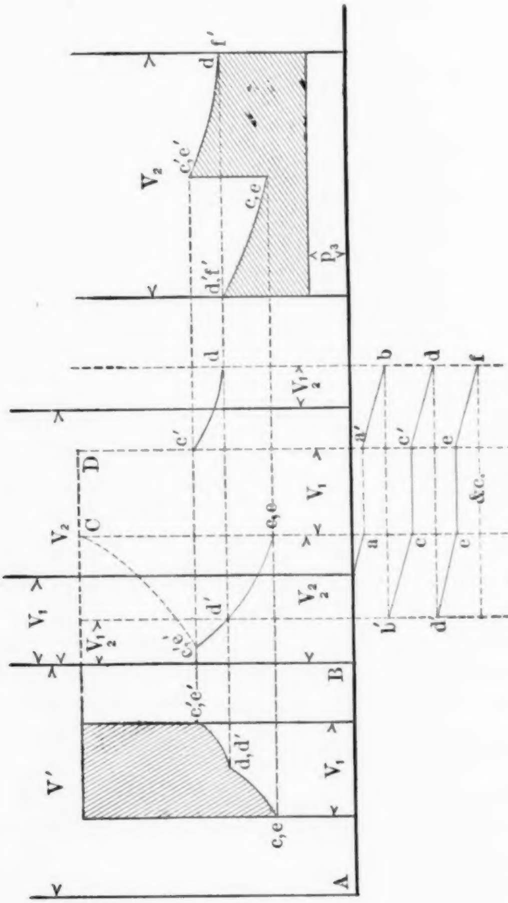


FIG. 12.

the L-piston at midstroke, while the volume in the receiver and connections is $V' + \frac{V_2}{2}$ as shown. Also the H-cylinder is ready to exhaust, and add the volume $aa' = V_1$. The line at $a'b$ is the variation of volume in the receiver and connections for the half-strokes shown for $a'b$ and ab in Fig. 11. Both pistons

move for this, one to reduce, and the other to enlarge the volume considered. The result is an enlargement to the point b, or to the volume $V' + V_2 + \frac{V_1}{2}$. Then the L-cylinder valves

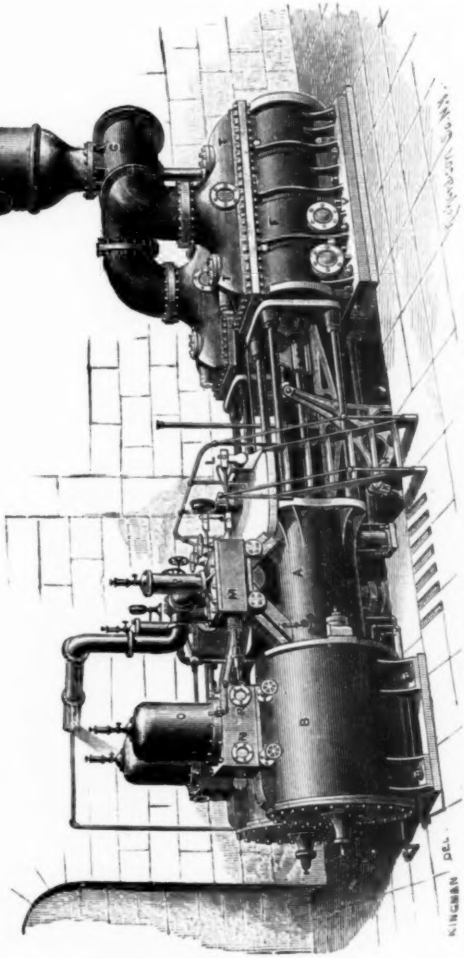


Fig. 13.—The Woolf Tandem Duplex.

are reversed, and the volume $bb' = V_2$ is cut off, leaving only $V' + \frac{V_1}{2}$. The volume $b'c$ is due to combined two half-strokes similarly as in $a'b$. Then cc' is like aa', etc.

Now the expansion line for the change of volume $a'b$, or $c'd$,

etc., is $c'd$ above, in the upper part of Fig. 12. This is drawn from A as the zero of volumes. Also the expansion line for $b'c$, or $d'c$, etc., is $d'c$ above. For this the zero is also at A. When the H-cylinder exhausts into the receiver and connections, the volume is raised from $V' + \frac{V_2}{2}$ to $V' + \frac{V_2}{2} + V_1$, or from C' to D; the steam following from a high-pressure point, C, giving the expansion line Cc', the latter meeting the compression line $cd'c'$ as shown. The resulting pressure is that for the point c'. The expansion from C is for a zero of volumes at D, as will be understood after studying Figs. 8 and 9.

The diagrams are drawn at one side and the other, to avoid confusing the figure.

Now as the H-cylinder exhausts, the pressure becomes that at c', when the H-piston begins its back stroke with a like back pressure. Owing to an increase of volume during this back stroke, the line that would be a compression line for this cylinder alone, becomes a falling or expansion line as shown; first, as far as to d while the L-piston makes a half-stroke; and then as continued to c for the other half, but with a diminishing volume in the receiver and connections. Hence, the lower line $c'dc$ of the H-cylinder card is a broken line as shown.

The L-cylinder expansion line is in two parts also, that at $d'c$ being due to the fall of pressure for the first half of stroke as traceable by lettering. At the midstroke there is a sudden rise of pressure cc', due to the exhaust of the H-cylinder into the receiver. From this point expansion continues on a new line due to a different pressure and volume.

Without entering into analysis, it is probably safe to predict that for an infinite volume the pressure in the receiver will be the same as by (60) and other equations; that is to say, the efficiency is still the same as previously given for an infinite receiver, and nearly so for receivers relatively large. Hence, when the receiver is very large as compared with the cylinders, and when there is no cut-off to either cylinder, the efficiency of engine remains very nearly the same, irrespective of the piston motion or valve motion. Whether there be an advantage in any form of valve or piston motion, for a finite receiver over the infinite, will perhaps be best shown by the numerical results subsequently given.

For the large receiver it is evident that expansion may be

obtained equally well, either with equal strokes and unequal cylinders, or unequal strokes with equal cylinders, or both combined.

In these discussions the engine itself is the only part of the machine brought into account, but in the practice of steam-pump engineering there are essential considerations relative to the pump as well, some of which have already been referred to.

V. The Tandem Duplex Compound Engine.

This engine differs essentially from the preceding by having four cylinders and no receiver.

Such an engine is shown in Fig. 13, in which there are four

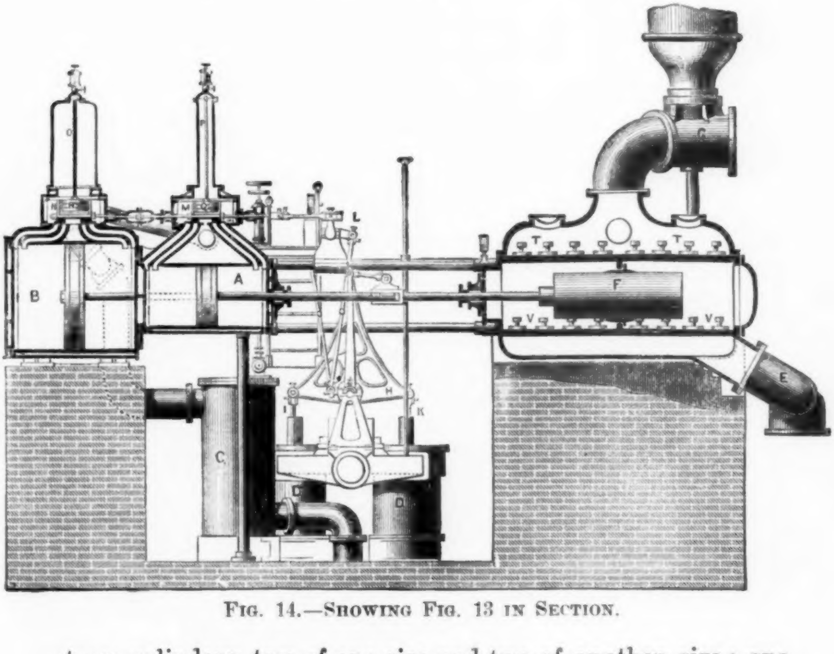


Fig. 14.—Showing Fig. 13 in Section.

steam cylinders, two of one size and two of another size; one large and one small cylinder are seen arranged in line of each one of the two piston-rods. The two on one piston-rod form one complete engine on the Woolf form.

Fig. 14 is a sectional view of the same engine, showing the relation of parts and the differing sizes of cylinders. The condenser is situated below.

Thermodynamically, however, it might be as well treated without the consideration of duplex, because in reality there are two distinct engines in this form of duplex. We will treat one part as covering the whole in principle.

Here one cylinder may be placed in line with the other, on a common piston-rod, and when so related the arrangement is called "tandem." But the arrangement is immaterial, provided the strokes are co-terminous and without tarrying. The steam is to be delivered directly from the high-pressure cylinder into the low, without the intervention of the receiver. Also, here the steam is supposed to be admitted to the *H*-cylinder for the full stroke, and full pressure of boiler; it is then to be exhausted, or transferred to the other cylinder during the whole stroke, which stroke is in common for the two pistons. In this way the volume of steam which occupies the *H*-cylinder at the end of one stroke, is expanded to the volume of the *L*-cylinder by the end of the next stroke.

If, as before, $V_1 =$ the volume of the *H*-cylinder, and V_2 that of the *L*-cylinder, we will have the ratio of expansion,

$$r = \frac{V_2}{V_1}.$$

The diagram for this case is shown in Fig. 15, with volumes and pressures indicated; also the indicator cards with shaded areas, the cards being drawn to the same scale of volumes.

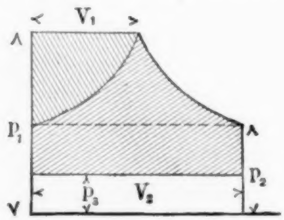


FIG. 15.

The formula for this case is well known. For each high-pressure cylinder full of steam the energy exerted, according to Rankine, is

$$U_1 = (P_m - P_3)\, V_2$$

where

$$P_m = P_1 \left(\frac{ir^{-1} - r^{-i}}{i - 1} \right)$$

where $i = m$ of table (2). Combining, we obtain

$$U_1 = P_1 V_1 \left\{ \frac{m}{m-1} - \frac{1}{m-1} \left(\frac{V_1}{V_2} \right)^{m-1} - \frac{P_3 V_2}{P_1 V_1} \right\} \qquad (61)$$

The efficiency is, as before,

$$\text{Efficiency} = \frac{U_1}{H}. \qquad (62)$$

The relation between the volumes and terminal and initial pressures is

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1} \right)^m. \qquad (63)$$

The effect of passage spaces between the cylinders has been considered under the III solution, where it is represented by V^1, great or small, including all space between valves in the passages, superheaters, etc.

In all the above solutions put V_1 for the sp. vol. in calculations for 1 lb.

Numerical Results for Comparison.

A few results have been computed and collected in the following table:

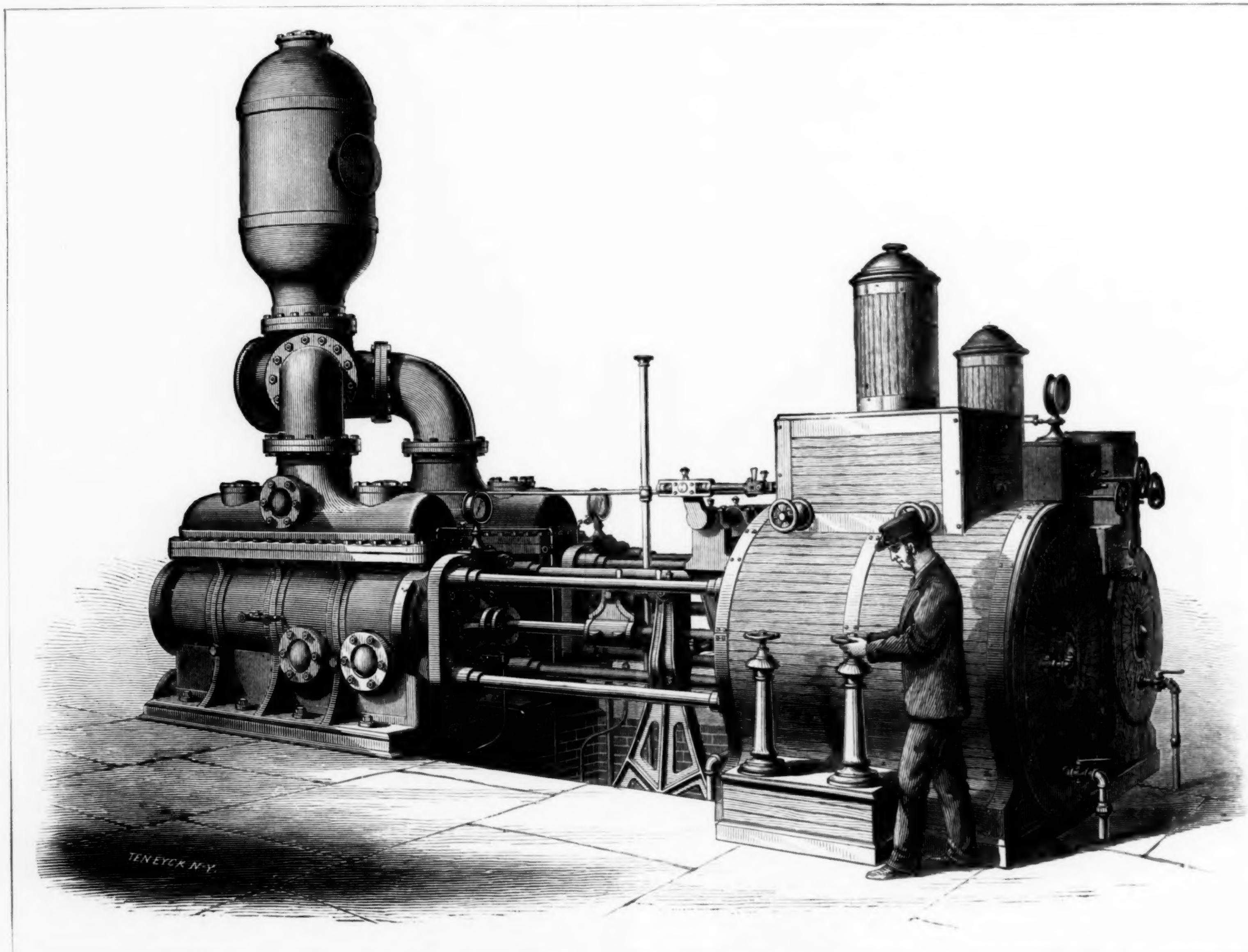
For the first column (16) was used, and for the second (48); that is, the complete formulas were put to the test.

The feed-water was assumed at the temperature 149° F., and the back pressure 3.62 pounds per square inch, absolute.

The exponent a was taken at $\frac{4}{3} = 1.3333$, n at 1.0456, and for the tandem engine, m was taken at 1.135. The value of a is probably too high for ordinary practice where steam is likely to be supersaturated; probably the best value for practice lies between 1.1 and 1.2.

TABLE OF RESULTS FOR THE I, II, AND V CASES.

P_1	$\frac{P_1}{P_2}$	$\frac{V_2}{V_1}$	*Effy.* I $V' = 2V_1$	*Effy.* II $V' = 2V_2$	*Effy.* $V' = \infty$, and Max. of I.	*Effy.* $V' = \infty$, $n = 1$, and Max. of I.	*Effy.* Tandem and Max. of II.	$\frac{\text{Work in } V_1}{\text{Work in } V_2}$ I	II	$V' = \infty$.	$V' = \infty$, $n = 1$.	$\frac{\text{Pressure of admission, } P_1}{\text{Pressure of exhaust, } P_2}$ I	II	$V' = \infty$.	Tandem
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
15.60	4.31	2	.0597	.0790	.0718	.0700	.0842	1.77	.78	1.01	1.	1.96	2.27	2.08	2.17
37.68	10.41	3	.0824	.1055	.0968	.0962	.1238	1.51	.86	1.03	1.	3.03	3.45	3.13	3.45
71.49	19.75	4	.0974	.1230	.1126	.1114	.1547	1.47	.83	1.04	1.	4.17	4.76	4.35	4.76
119.2	32.91	5	.1060	.1326	.1217	.1213	.1755	1.47	.90	1.05	1.	5.26	5.88	5.26	6.25



THE TANK COMPOUND ENGINE WITH UNEQUAL CYLINDERS.

In looking over the table we at once notice the glaring fact that the tandem engine excels all the others in efficiency, and by a considerable percentage. At 23 pounds per square inch apparent pressure, the excess of efficiency of the tandem over the II, is about 17 per cent. of the efficiency of the latter. For 104 pounds per square inch apparent pressure, the same is about 32 per cent.

A second important fact respecting the two valve movements, viz., that of the I and II, is that the latter is a high percentage above the other.

A third important fact appearing in the table, is that in the II movement, the efficiency is a very considerable percentage greater when the receiver is small than when it is infinite, a fact in support of the conclusions of solutions of II and III. Compare columns 5 and 6. For the 5, the receiver is only twice as large as the low-pressure cylinder, and yet the efficiency here is from 8 to 10 per cent. higher than for the engine with an infinite volume.

For I, however, the case is the reverse, but in a greater ratio; that is to say, the efficiency is lowered from 13 to 17 per cent., by changing the receiver from an infinite volume to one only twice as large as the low-pressure cylinder.

As to the value of n, it appears that the efficiency does not change materially when n changes from 1 to 1.0456.

LXV.

THE SPECIFIC HEAT OF PLATINUM AND THE USE OF THIS METAL IN THE PYROMETER.

BY

J. C. HOADLEY, BOSTON, MASS.

In a paper which I had the honor to present to the American Society of Mechanical Engineers at the meeting held at Hartford in May, 1881, I gave, as the best estimate of the mean specific heat of platinum which I was able to form—based on the data to be found in Clark's "Constants of Nature"—0.0333, equal to one-thirtieth of the specific heat of water under standard conditions; and apparently uniform, or nearly

so, at all temperatures ordinarily attainable. At the same time I stated that a careful study of the original memoirs might disclose such reasons for assigning greater weight to the results obtained by some experimenters than to the varying results obtained by others, as to lead to a probable mean result much more trustworthy than that of my first crude approximations.

Such a study of the original memoirs, and a careful discussion of the several experiments therein described, for which I had neither the requisite facilities nor the necessary leisure, was made during his summer vacation by Mr. Silas W. Holman, Instructor in Physics at the Massachusetts Institute of Technology, who generously placed at my disposal the interesting and valuable fruits of his labors.

Mr. Holman first clearly points out the distinction between the terms "true specific heat" and "mean specific heat." The *true* specific heat of any substance at $t°$, is the amount of heat, expressed in heat units, required to raise the unit weight of the substance from any temperature $t°$ to $t° + 1°$, or more properly from $t°$ to $t° + dt$, whence we may write the true specific heat at $t° = \frac{dh}{dt} =$ first differential coefficient of the heat with regard to the temperature (of course not passing through change of state, as from solid to liquid, or from liquid to gaseous).

On the other hand, the *mean* specific heat from 0° to $t°$ is the amount of heat, expressed in heat units, required to raise the unit of weight from 0° to $t°$, divided by the number of degrees of this temperature $t°$, 0° in this case being 0° C. For Fahrenheit degrees the equivalent expression is the amount of heat required to raise the unit weight from 32° to $t°$, divided by the number of degrees embraced between 32° and $t°$.

Confining ourselves, for the sake of simplicity, to Centigrade degrees, for the present, let h_t, h_{t_1}, etc., = number of heat units required to raise unit weight from 0° to $t°$, $t_1°$, etc., respectively. Then let $\frac{h^t}{t}$ $\frac{h_{t1}}{t_1}$, etc., = mean specific heat from 0° to $t°$, $t_1°$, etc., respectively. Also, $h_{t1} - h_t =$ number of heat units required from $t°$ to $t_1°$. Then $\frac{h_{t1} - h_t}{t_1 - t} =$ m. sp. ht. from $t°$ to

$t_1°$. Now $h_t = t(a + bt + ct^2 + \ldots \ldots \ldots \ldots \ldots$ etc.), and $h_{t1} = t_1(a + bt_1 + ct_1^2 + \ldots$ etc.),

$$\therefore h_{t1} - h_t = a(t_1 - t) + b(t_1^2 - t^2) + c(t_1^3 - t^3) + \ldots \text{ etc.}$$

$$\therefore \frac{h_{t1} - h_t}{t_1 - t} = a + b(t_1 - t) + c(t_1^2 - 2tt_1 + t^2) + d(\ldots \text{etc.})$$

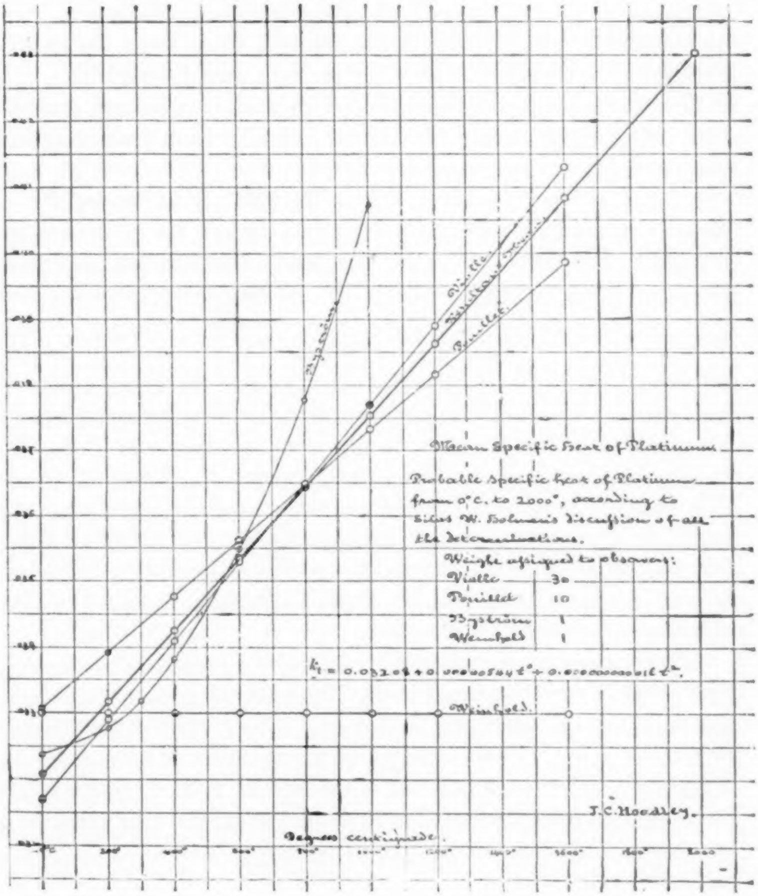


FIG. 17.

which, at the limit when t_1 approaches t, becomes the *true* specific heat at $t° = \frac{dh}{dt} = a + 2bt + 3ct^2 + 4dt^3 + \ldots\ldots$ etc., while the *mean* specific heat from 0° to $t° = \frac{h_t}{t} = a + bt + ct^2 + dt^3 + \ldots$ etc.

The neglect of this obvious distinction, and the confusion of *mean* with *true* specific heat, vitiated my work. The location of points on my diagram, representing mean specific heat determinations at points midway between the two extremes for which the determinations were made, was erroneous and confusing. For instance, the determination 0.03818, for the mean specific heat 0° to 1200 C., should have been located at 1200° on my diagram, instead of at 600°, as I located it.

Mr. Holman also introduces Violle's results for the specific heat of platinum which he considers the best results by far which we possess.

In discussing the results Mr. Holman remarks, as I had already done, that every observer has found for platinum an increase of specific heat with increase of temperature, and that the *rates* of increase found by the various observers are not very diverse. In the expression $\frac{h_t}{t} = a + bt + ct^2 + dt^3 +$ etc., we wish to find the most probable values of the constants, a, b, c, d, etc., up to a limiting temperature, $t =$, let us say, 1600° C. Now, of these constants a is the *true* specific heat 0° C. To obtain this, we may, if we choose, collect all observations at this temperature, and, giving proper weight to each, take the mean, this constant being entirely independent of the others. Mr. Holman has chosen another method, by which, however, he has arrived at almost identically the same results which the above method would have given.

Taking each trustworthy set of observations, he has found, by the graphical method, or by the method of least squares, the value of a, b, and c, for that set, if the experimenter has not done so himself. Then calculating for a series of temperatures sufficiently near together—at intervals of 200° C. up to 1600° C., the mean specific heat for that temperature—and assigning to each set its proper weight, as nearly as may be, he takes a mean of each column.

From these means may be immediately calculated the values of a, b, and c. Higher powers than the square of t are useless in the present state of our knowledge, and even that may be discarded in the case of platinum; but it must be retained in the case of all other substances.

But if we prefer a value of a deduced from more observations, or from any particular set of low temperature obser-

vations, we can introduce such value without affecting the accuracy of the values of b and c. Mr. Holman gives in a table, which I reproduce, a summary of his interesting and valuable labor on platinum, and, further on, a summary of the results of various observers. To Violle he gives a weight of 30, as his determinations have the widest range (except Pouillet's, which have the same range), and are, in Mr. Holman's opinion, by far the most thorough, careful, and accurate, Violle being a skilful observer. To Pouillet's determinations Mr. Holman assigns a weight of 10, as having the same range as Violle's, but without the advantage of all the facilities for accurate work possessed by the latter. Byström's results are apparently pretty good, but extend only to 300° C., and are therefore entitled to but little weight when extrapolated to 1600° C.

Weinhold's results have not equal concordance among themselves, nor do they appear to have been made with the same degree of care and skill as even Pouillet's.

To Byström's and Weinhold's determinations, which he considers of little value, Mr. Holman assigns a weight of one each.

In all cases it will be noted that the temperatures are upon the air thermometer.

Mean Specific Heat of Platinum from 0° to t° C.

Observer.	Wt.	$t° = 0°$	200°	400°	600°	800°	1000°	1200°	1600°
Violle, . . .	30	.0317	.0329	.0341	.0353	.0365	.0377	.0389	.0413
Pouillet, . .	10	.03307	.03392	.03477	.03562	.03649	.03732	.03817	.03987
Byström, . .	1	.03239	.03278	.03381	.03547	.03778	.04073	.04431	.05341
Weinhold, .	1	.0330	.0330	.0330	.0330	.0330	.0330	.0330	.0330
Means, . . .		.03208	.03315	.03423	.03533	.03645	.03758	.03871	.04105

From the above means Mr. Holman deduces approximations which he considers sufficiently exact as the mean specific heat from 0° to $t°$, $k_t = 0.03208 + 0.00000544t° + 0.000000000016t^2$, or, if ct^2 be dropped, $k_t = 0.03208 + 0.00000547t$, for platinum.

It will be observed that when the third term, ct^2, is omitted, Mr. Holman's curve, when represented graphically, becomes a

straight line, and that the eighth decimal in the constant b becomes 7 instead of 4.

Mr. Holman deduces in a similar manner, but with less exactness, on account of the paucity of material, the probable mean specific heat of iron from 0° C. to 300°, 600°, and 1000° C., as exhibited in the subjoined table :

Mean Specific Heat of Iron from 0° to t° C.

Observer.	Wt.	t = 0° C.	300°	600°	1000°
Weinhold, ...	5	.10591	.13150	.16907	.2378
Bêde, ...	3	.1053	.1266	.1479	.1763
Byström, ...	2	.11164	.11703	.13100	.1629
Means, ...		.10687	.12714	.15510	.2044

From these means is deduced the following equation for the mean specific heat of iron :

$$k_t = 0.10687 + 0.0000547t + 0.0000000428t^2.$$

In this expression, the third term, ct^2, cannot be neglected ; the line is distinctly a curve. These constants are in all cases for Centigrade degrees, and must be multiplied by $\frac{5}{9}$ to reduce them for Fahrenheit degrees. Performing this multiplication, the expressions become, in Fahrenheit degrees :

For the mean specific heat of platinum, from 32° to t° F. :

$$k_t = 0.03208 + 0.000003022\,(t - 32) + 0.000000000009\,(t - 32)$$

or, omitting the last term, as we may safely do, for platinum :

$$k_t = 0.03208 + 0.0000034\,(t^\circ - 32).$$

For the mean specific heat of iron, from 32° to t° F. :

$$k_t = 0.10687 + 0.0000304\,(t - 32) + 0.0000000238\,(t - 32)^2.$$

For pyrometric purposes, iron and all other metals save platinum may be left out of consideration. For platinum, my assumption of $.0333 = \frac{1}{30}$, as the uniform specific heat at all ordinary temperatures, is found to be correct only at a certain

temperature, namely, 446.195° Fahr., equal to 230.108° C. At all temperatures below this, my assumption, 0.333, is too high; at all higher temperatures, it is too low.

The rate at which the mean specific heat changes is, per degree F., 0.00000304 deg.

For the 32° F. between 0° F. and 0° C., the difference in m. sp. h. is $32 \times 0.00000304 = 0.00009728$, and this difference subtracted from the mean sp. h. of Pt. at 0° C. will give the m. sp. h. of Pt. at 0° F. thus: $0.03208 - 0.00009728 = 0.03198272$.

Of course we may substitute this value of the first term, a, this number, .031983 (specific heat of platinum at 0° F.), for the number in the table, 0.03208 (sp. ht. of Pt. at 32° F.), when t° will be the temperature F. from 0° F., and the 32° must not be subtracted from t.

The assumption, 0.0333, for the first approximation in proportioning the pyrometer, is a very convenient one. Quite correct for the temperature indicated by 446.195° F. = 230.108° C., which is about the upper limit of accurate indication by the mercurial thermometer, the corrections to be applied from this point upward are all in the same direction, all *minus*. For example, 1050.4° observed, = 1000° corrected; 2022.4° observed, = 1800° corrected.

The subjoined table has been computed for the Fahrenheit scale and zero, by the use of the formula

$$k_t = 0.031983 + 0.0000030422\,(t - 32) + 0.000000000009\,(t - 32)^2.$$

The corrections *below* 446.195° are *plus*.

The lines 32° and 212° are inserted for convenience in testing the pyrometer for verification. At 32° true temperature the indicated temperature is 30.8°, a correction of + 1.2°. At 212°, or the boiling-point, the indicated temperature is 207.5°, a correction of + 4.5°. In my pyrometer the water and so much of the metal as shares its temperatures being together equal to 2 lbs. of water, and the platinum ball being 0.6 lb., and the assumed sp. ht. $\frac{1}{30}$ that of cold water, the assumed ratio is 100 to 1; and with good thermometers having about 0.8 in. to 1° – graduated to 0.1°, on which $\frac{1}{40}$ or even $\frac{1}{50}$ of a degree can be accurately read, the greatest error need not exceed 6°. By skilful manipulation, error is nearly eliminated.

It will be observed that the table is carried up to 4000° F., the reputed melting-point of platinum.

Temperatures, in deg. Fahr., corresponding with specific heat in column 2.	Mean sp. ht. of platinum, computed for each 100 deg. Fahrenheit.	Differences of sp. ht. per each 100° Fahrenheit.	Ratio of computed to assumed sp. ht., viz.: $\frac{1}{30}$ water = 0.033333.	Differences of ratios for each 100° Fahrenheit.	Observed loss of temperatures by platinum at assumed ratio of sp. ht., 30 to 1.	Differences of observed temperatures per 100° Fahrenheit.
1	2	3	4	5	6	7
0	.031983		.95950		0.0	
32	.032080		.96240		30.8	
100	.032286	303	.96857	907	96.9	96.9
200	.032588	302	.97764	907	195.5	98.6
212	.032624		.97783		207.5	
300	.032891	303	.98672	908	296	100.5
400	.033193	302	.98580	908	398.3	102.3
446.195	.033333		1.00000		446.2	
500	.033496	303	1.00489	909	502.4	104.1
600	.033800	304	1.01399	910	608.4	106
700	.034103	303	1.02309	910	716.2	107.8
800	.034406	303	1.03219	910	825.8	109.6
900	.034710	304	1.04130	911	937.2	111.4
1000	.035014	304	1.05042	912	1050.4	113.2
1100	.035318	304	1.05954	912	1165.5	115.1
1200	.035622	304	1.06867	913	1282.4	116.9
1300	.035927	305	1.07780	913	1401.1	118.7
1400	.036231	304	1.08694	914	1521.7	120.6
1500	.036536	305	1.09608	914	1644.1	122.4
1600	.036841	305	1.10523	915	1768.4	124.3
1700	.037146	305	1.11438	915	1894.5	126.1
1800	.037451	305	1.12354	916	2022.4	127.9
		306		917		129.7

Temperatures in deg. Fahr., corresponding with specific heat in column 2.	Mean sp. ht. of platinum, computed for each 100 deg. Fahrenheit.	Differences of sp. ht. per each 100° Fahrenheit.	Ratio of computed to assumed sp. ht., viz.: $\frac{1}{30}$ water = 0.033333.	Differences of ratios for each 100° Fahrenheit.	Observed loss of temperatures by platinum at assumed ratio of sp. ht., 30 to 1.	Differences of observed temperature per 100° Fahrenheit.
1	2	3	4	5	6	7
1900	.037757		1.13271		2152.1	
		306		917		131.7
2000	.038063		1.14188		2283.8	
		305		917		133.4
2100	.038368		1.15105		2417.2	
		306		918		135.3
2200	.038674		1.16023		2552.5	
		307		919		137.2
2300	.038981		1.16942		2689.7	
		306		919		139.0
2400	.039287		1.17861		2828.7	
		307		920		140.8
2500	039594		1.18781		2969.5	
		306		920		142.7
2600	.039900		1.19701		3112.2	
		307		921		144.6
2700	.040207		1.20622		3256.8	
		307		921		146.4
2800	.040514		1.21543		3403.2	
		308		922		148.3
2900	.040822		1.22465		3551.5	
		307		923		150.1
3000	.041129		1.23388		3701.6	
		308		923		152.0
3100	.041437		1.24311		3853.6	
		308		923		153.9
3200	.041745		1.25234		4007.5	
		308		924		155.7
3300	.042053		1.26158		4163.2	
		308		925		157.6
3400	.042361		1.27083		4320.8	
		308		925		159.5
3500	.042669		1.28008		4480.3	
		309		926		161.3
3600	.042978		1.28934		4641.6	
		309		926		163.2
3700	.043287		1.29860		4804.8	
		309		927		165.1
3800	.043596		1.30787		4969.9	
		309		927		166.9
3900	.043905		1.31714		5136.8	
		309		928		168.8
4000	.044214		1.22642		5305.6	

Since the highest temperature at which the sp. ht. of platinum has been determined is 1200° C. = 2182° F., all the numbers in the table above 2200° must be received with a certain degree of gradually increasing reserve; and the analogy of other metals leads us to suppose that between 3000° and 4000° the specific heat may rise more rapidly than the formula indicates. There can be no great error up to 3000°, and between that limit and 4000° it can only be said that the figures here given are the best attainable, and if of little practical use are better than none.

Note.—From the observed loss of temperature in column 6, find the corresponding *true* loss, in column 1, and to this add the temperature of the water in pyrometer after the immersion of the platinum, to obtain the true temperature of the platinum at immersion.

This method of using the table gives a result slightly in excess of the true temperature, usually 0.5 per cent. to 1 per cent., depending on the temperature of the *water* after the immersion of the platinum.

To give *exact* results, the table should be calculated for mean sp. ht. from the final temperature of the water (after immersion), instead of from 32° F., to the several upper limits, varying by 100° up to 4000°.

This would be impracticable without a separate table for each temperature, varying by 1°, or by a small number of degrees, within the range of the initial and final temperature of the water, say 40° to 100°.

By adding the final temperature of the water, after immersion, to the loss of heat by the platinum heat-carrier, in *Pyrometer* degrees (*i. e.*, the product of the rise of *t*, of the water in degrees F., or more exactly, the increase in British thermal units—multiplied by the ratio of the heat-capacity of the water to the assumed heat-capacity of the platinum heat-carrier, 100 to 1, normally), and finding in column 6, by the aid of the differences in column 7, the corresponding number, the number opposite in column 1 will be *very nearly* the true temperature of the heat-carrier at the instant of its immersion.

Added since the Meeting.

A closer approximation may generally be made, by adding to the product of the rise of temperature of the water or of heat in British thermal units, multiplied by the ratio of the heat-capacity of the water to the assumed heat-capacity of the heat-carrier, the temperature of the water after immersion; then finding the corresponding number in column 6 by the aid of the differences in column 7, and taking the number opposite in column 1. The temperature so found will rarely differ from that worked out by the formula by more than 0.1 of *one per cent.* J. C. H.

LXVI.

CHRONOGRAPH FOR ENGINEERING PURPOSES, WITH THE HIPP ESCAPEMENT.

BY

W. R. ECKART, C.E., SAN FRANCISCO, CAL.

Having for a number of years felt the need of some instrument for measuring and recording the velocity of pumping machinery with which I have been brought in contact professionally at the deep mines on the Comstock Lode, where the irregularities due to long and heavy pump-rods, as well as other masses in motion, were greatly felt, I was forcibly impressed with an article by Robert Briggs, C.E. (*Journal Franklin Institute*, 1877, page 89), describing the "Hipp Escapement" and its adaptability to the purposes I desired.

I corresponded with that gentleman, and he had constructed for me, in Philadelphia, the escapement and driving-gear now used (for a detailed account of the Hipp escapement I must refer to his paper on that subject); but the revolving drum and other arranged parts of the instrument had to be changed, as no way of recording the curves of motion on paper could be used that produced perceptible friction (such as pencils or ink); and on account of the exceeding sensitiveness of the controlling spring of the escapement, great care was required in securing a perfect balance of the revolving drums with ease of motion, without the use of heavy driving weights; in other words, all parts of the instrument had to be made as sensitive

as possible, so as to require the least possible weights to produce the desired motion.

In the start numerous failures had to be put up with from not paying attention to these points of construction, and even now, if the recording paper is not properly put on the revolving drum, a slight excess of weight on one side of the drum, such as that due to lapping the paper, will produce a perceptible change of sound from the escapement-spring, indicating an acceleration or retardation of motion, according as the excess is on the descending or ascending side of the drum. In covering the drum with paper I have found it desirable to cut the sheets some $\frac{3}{8}$ or $\frac{1}{4}$ inch less than the exact circumference of the drum, and to unite the edges by means of a strip of paper, mucilaged and lapping slightly on each edge. The whole joint is then thinned down with fine sandpaper to equal weight and smoothness; the whole sheet is covered with a coating of lampblack from a suitable hand-lamp, and is then ready to receive the curve of motion.

The tracers, both for recording seconds as well as the velocity curve of the engine, are made of flat strips of spring steel, the axis of each being pivoted at the end on adjustable screw-centres, to prevent loss of motion. By means of a small steel wire and weight extending to the opposite side, the tracers can be made to bear as lightly as desirable on the paper, and, when properly adjusted, the pressure is only sufficient to remove the lampblack without touching the paper, thereby leaving a fine white line on the dark background with the least possible interruption of motion. The whole is permanently set by dipping the face in a thin solution of shellac.

Instead of using a pendulum for producing (through an electro-magnet) the marks spacing seconds on the paper, which is the usual device, some other method was found necessary that would admit of greater compactness and portability, for the chronograph was to be used not only on the surface, where the pumping engines were situated, but it had to be adapted to underground use, and those who are acquainted with the general arrangement of a deep mine pumping compartment, especially on the Comstock, where the air is heavily surcharged with steam from the excessively hot water of the mines, know that the difficulties to be overcome were not slight, and compactness was absolutely necessary, as the whole instrument when

in use, had not only to be protected from the steam and dripping water, but had to be set up in such cramped spaces as could be found available, without any further preparations, and the time for adjusting the instrument as a whole, ready for use, had, in all cases, to be as limited as possible, as the temperature in which I was obliged to take diagrams sometimes reached 110°.

After numerous experiments the use of a chronoscope (or timer), such as is to be had for timing horse races, was made to give satisfactory results. (See Fig. 18.) The method adopted was as follows: A stand or base-plate, upon which the timer was placed, had a brass stanchion suspending a fine platinum wire directly over the second-hand; this wire, when at rest, bore on a piece of platinum inserted in a rubber insulator projecting from the stanchion, each of these wires being connected in the usual manner through the electro-magnet on the chronograph to a two-cell battery. A circuit was always formed except when the hand of the timer, revolving once every second, swings the suspended wire free from its metal bearing at the apex of the triangular notch cut in the rubber guide-piece; as contact was broken every revolution of the second-hand, the armature recorded the same by a side movement of the steel tracer resting on the prepared paper of the drum.

The suspending wire was made adjustable in various directions to suit the second-hand, and, when once adjusted, the whole instrument was covered with a glass case protecting it from moisture, and could be transported and used with rapidity and without further difficulty.

Mr. Briggs states (in his paper above referred to) that Professor Hilgard used a chronoscope for the Navy Ordnance Department, in which the second marks were 30 inches apart. I have found no trouble in speeding the revolving drum of 6″ diameter, until the second marks were 20 inches apart, but for practical use, a length of three to ten inches (depending somewhat on the engine speed) was all that was desired, and by use of a standard steel scale, with the inch divided into hundredths, changes of motion taking place in the $\frac{1}{1000}$th part of a second were easily read and recorded without trouble, and the crossing of lines due to the too frequent revolution of the recording drum during one stroke of the engine was avoided. The

use of the small electro-magnet—on the tracer carriage, to raise for an instant the tracing pointer off the drum at any desired point—was found necessary in determining the effects of elasticity in the interruption and variation of motion, where a *long* line of pump-rods was used, and was also found useful in fixing positively the exact point of closing or opening of the steam valves of the engine, independent of all reference to the indicator cards taken.

Two drawings, giving different views of the chronograph as constructed and used, are attached to this article, exhibiting details of construction to complete what otherwise might be considered a defective description of the instrument.

It may not be out of place here to state that the instrument has been successfully applied to several of the different types of large pumping-engines found on the Comstock Lode, such as direct-acting fly-wheel engines, geared pumping-engines, and the "Davy engines;" it has also been used to determine the motion and relative motion of pump-rods, and pumps some 2500 feet below the surface-engine driving the same, and at intermediate points. The results are exceedingly interesting and instructive, and as numerous indicator cards were taken from the engines and pumps simultaneously with the motion diagrams, nearly all conditions of motion and power, during the time under consideration, were definitely determined, and may hereafter form the subject of other papers when time will permit.

Some very important results of the elasticity of long pump-rods are clearly set forth in one case: A rod at a point 1800 feet below the surface showed a positive pause, while the engine driving it was nearly at its point of maximum motion, and pumps attached to the rods may have, and do have, strokes in excess of or less than the *stroke of engine driving the same* and to an *important extent.* Hence, I think, it can be definitely stated that any consideration of motion of pumps, or discharge capacity, driven by a long line of pump-rods based upon the motion or stroke of a surface-engine alone, will in no way be even approximate unless the elasticity and effects of counter-balancing by balance bobs on that elasticity is also considered.

The effects of different degrees of compression upon the engines and motion of the pump-rods in passing the centres have been considered, and the diagrams clearly show the im-

portance of considering it in connection with the strength of the rods and balance bobs.

My latest use of the instrument in conjunction with an engine test has been to determine, if possible, the rate of condensation of steam per second in the steam cylinders of a pumping-engine, where the change of motion due to each fractional part of the stroke was determined. Also, a ten hour experiment trial, to show the economy of compression, as compared with a ten hour trial of the same engine on the succeeding day, where no compression was used (otherwise all conditions being similar), has been made, when changes of velocity of piston were determined by the chronograph. I hope some time to make public the results of these observations for the use and criticism of those interested, after the labor of working them up and tabulating them is completed.

While it is well known that a committee of the British Association applied a chronograph of Morin's type in 1843-4, to the determination of the velocity of piston for a Cornish pump-engine, I believe there was no application of the instrument to the rods below ground, and, from published records at my command, I am led to believe that this is the first application of a chronograph of sensitive construction ever made to pit work and the other purposes so briefly mentioned.

Lettered Reference to Figures 18 *and* 19 *of the Instrument.*

C C—Cast-iron base-plate, covered with sheet-brass, upon which the mechanism is secured.

B—Metal frame containing gearing for driving drum A and escapement-wheel *b*; motion communicated by means of adjustable weights D.

A A—Light brass drum, accurately balanced, revolving on friction rollers 8, 8, at both ends.

f f—Parallel guide bars upon which the tracing-point h_0 and its carriage travel back and forth, receiving motion in one direction from the engine or other moving parts through the cord P, passing through the bars *f*, and attached to the tracing carriage; the return motion is derived from a coiled spring in the spring drum C.

e e—Small electro-magnets on tracing carriage for raising the tracing-point h_0 off the paper and replacing it at any desired point to be especially observed.

d—Electro-magnets on separate carriage *kk*, adjustable on parallel bars *f*, operating the steel tracing-point *g*, attached to the armature of *d*, for the purpose of recording seconds on the margin of the paper or at other parts of same as required.

i—Chronoscope or watch supported on frame *x*, the second-hand of which swings the light platinum wire J, breaking contact with the insulated wire *k*, thereby breaking circuit with *d* and recording seconds through the tracing-point *g* on the paper.

q—Adjusting screw for the wire J.

a—Steel spring of escapement. This spring is securely clamped in Y, its flexibility being controlled to a certain extent by means of the thumb-screws *o* and *p*.

Discussion.

Professor Thurston: When Mr. Eckart was about to begin his work on this subject, I suggested that he first describe the apparatus he proposed using, and his methods, and finally give us a carefully worked-up series of papers on the result of those methods. He has an instrument that can measure time to the thousandth of a second, which can give us velocities with such precision that we can measure the variation of the piston from the harmonic motion with perfect accuracy. Mr. Eckart has set himself about the preparation of such a series of papers, and this, although perhaps the least important of all, is interesting. He is a very careful worker. In fact, I have not met in the profession a man who seemed better adapted to the application of fine measurements to experimentation on the steam-engine. The paper gives his general idea of the machine, and the drawings will show you very exactly what the instrument is. In the first place, there is a revolving drum. An escapement gives it a perfectly smooth and perfectly uniform motion. It is capable of very exact adjustment. It is so delicate in its operation, that in fitting a piece of smoked paper on the surface of the cylinder, it is necessary at the point where the parts lap, to smooth it down with sand-paper until the thickness through the lap is exactly the same as the thickness of the rest of the sheet. So Mr. Eckart covers this brass cylinder with a sheet of very thin smooth paper, which has been given a coating of soot. That

coating is just thick enough to perceptibly cover the paper. He wraps his paper around and makes a joint where he can, and then smooths down that joint until it is of exactly the same thickness as the rest of the sheet. His cylinder revolves at a suitable uniform rate of speed for the velocity of his engine, and now the problem is to procure upon that revolving cylinder a mark, a curve, that shall represent the motion of the engine with exactness. There is a little carriage, which can be drawn backward and forward on two wires, which form its travelling way, by a cord which is led to the cross-head or some other part of the engine, and it moves back and forth on that pair of rods, with exactly the motion of the piston. That carriage carries a pair of electro-magnets which actuate a little pointer, which is pinned down, and just touches the soot on the paper without touching the paper itself; and as that moves backward and forward, a succession of sparks is passed from the battery, and those sparks prick the paper, remove the soot at the point of contact, or the pointer itself will just touch the soot and scrape it away; sometimes one method is tried and sometimes another. I think Mr. Eckart allows the point to touch; and as this little carriage thus moves backward and forward, that pointer will describe a curve on the paper, which is a perfect record of the velocity of the piston throughout its stroke. Then, in order to get a time movement, he attaches another pair of electro-magnets, which move another pointer of the same kind, but which is stationary at a certain point in the length of the motion. That pointer if left to itself will describe simply a circle. At the end of each period he wishes to measure, connection is formed here with a battery, and that pointer is thrown out of place by the action of these electro-magnets, and that produces a little indentation in the line, and that marks the end of a second, or end of a quarter second, as the case may be. Now divide up that interval, which may be several inches on the cylinder, into as fine parts as you choose, and you so measure your time into as small a fraction of a second as you like. Again, there is a time pointer at one end of the machine, touching the soot on the paper at that point, and a carriage which traverses the bar synchronously with the motion of the engine. Also, there is a time-piece, an ordinary time-keeper's watch, which is set in a little case, and that makes and breaks the circuit. With such an instrument, properly made and adjusted, we have in our

hands a power to make experiments with a steam-engine, and acquire data that never could be obtained before.

MR. WOODBURY: What relation does the length of that cylinder which is covered with paper, bear to the length of the stroke of the pump or engine?

PROFESSOR THURSTON: I am not certain whether he gives the size. I cannot answer that question. The instrument has been used in the mines of the Comstock Lode. You may judge something from the size of the watch of the size of the instrument. But the instrument has been very carefully made. He sent me some of the curves obtained from pumping-engines, in which, although the engines had a balance-wheel that weighed something like a hundred tons, the effect of a change of compression of one notch, without any other change, is seen in the change of speed in the engine as it brings up on that cushion of steam. It is wonderfully fine work.

MR. WOODBURY: As these meetings are for the interchange of experience, I would make bold to refer to some work of my own upon that same subject.

At the test of the Lowell pumping-engine in 1873, the commission wished to measure the velocity of the fly-wheel at consequent points in each revolution, in order to ascertain the extent and perhaps the cause of its variable motion. I tried a chronograph from the physical laboratory of a scientific school in Boston, but the tremor of the pumping station and the poor quality of the clock-work rotating the drum, vitiated all of the results.

Subsequently, I devised an apparatus, which operated satisfactorily on this and other engines. In previous chronographs, the results have been obtained by recording on a drum moving with a uniform rotary motion, the closing of an electric circuit at the intervals required to be measured, the regular closing of the circuit by clock-work being really a check upon the motion of the revolving drum. For this work, I reversed the relation of the various portions of the chronograph by applying the irregular motion to the pulley carrying the record, which was made on a strip of telegraph paper by a pencil attached to the armature of an electro-magnet, whose circuit was closed at regular intervals.

The apparatus was contained in a box a foot and a half long, a foot deep and about four inches wide, and is shown in Fig. 20.

It consists of a pulley mounted on a shaft, which terminates in a wedge, like a screw-driver, which is held against a slot across the centre at the end of the shaft carrying the fly-wheel; so that the motion of this pulley coincides with that of the fly-wheel. As it revolves, a band of telegraph paper, supplied by a reel, passes around it. A pencil pressed down by a spring and placed directly over the pulley is attached to the armature of an electro-magnet.

The circuit is closed two hundred times a minute by means of a marine clock arranged in the following manner:

A very fine hole was bored in the end of the pallet arbor, and a pin about half an inch long firmly inserted; on this pin a copper wire shaped like an inverted ∩ was attached at its centre of gravity and vibrated in unison with the escapement.

Underneath the ends of this copper wire two drops of mercury connected with the wires in such a manner that when the ∩ was in a vertical position, the points would touch the meniscus of the mercury, and the current passing through the wire from one drop of mercury to the other would close the circuit.

This furnished a means of rapidly closing the circuit by the use of simple and portable apparatus. This arrangement was so accurately balanced that it did not prevent the clock from keeping correct time, as shown by a comparison with a chronometer for several days.

A telegraph key, designed for the purpose, was fastened on the engine in such a manner as to close the circuit when the crank passed over the centre.

When the circuit was open, the pencil would trace a straight line on the paper; when it was closed, either by the clock or the key, the electro-magnet would draw the pencil to one side, thereby producing a sharply defined serration on the paper. By measuring the distances between these serrations, the velocity is determined. Thus, if such a distance measured two inches, and the time intervening between two consecutive closings of the circuit was one two-hundredths of a minute, the velocity of the face of the pulley would be $2 \times 200 = 400$ inches per minute or 0.556 feet per second.

By means of the key recording the position of the crank, the position of the various points whose velocity is thus indicated is thus given for a number of points in each revolution; and the instrument will record many consecutive revolutions, each time

making a series of measurements for different positions of the crank.

These curves represent the velocity of a point on the fly-wheel five feet from the centre, the ordinates showing the velocity in feet per second, and the abscissæ, the position of the crank. At zero the crank is in a vertical position, the crank-pin being over the centre; at 25 the crank-pin is horizontal with the centre; at 50 it is below the centre; at 75 it is horizontal with the centre; and at 100 it is in the same position as at zero.

The following table gives the elements of the curves (see Figs. 21, 22), of two well-known beam-pumping engines, and that of a horizontal stationary engine which gave trouble by its irregular motion. Much of the difficulty could have been remedied by the use of a heavier fly-wheel, as the speed of the engine could not be increased for this special work, and also by using steam at a lower pressure and following a greater portion of the stroke.

Of course, such devices would be only make-shifts to reduce inherent faults in an engine which was manifestly unfit for the work assigned to it.

TABLE SHOWING VELOCITY OF FLY-WHEELS AT POINT 5 FEET FROM CENTRE.

Portion of Revolution.	Lowell Pumping Engine.	Lynn Pumping Engine.		Horizontal Engine.
	Revolutions per minute.			
	13.26	18.61	13.90	19.39
	Velocity in feet per second.			
.00	6.42	9.80	7.13	10.16
.04	6.46	9.82	7.27	10.62
.08	6.54	9.92	7.53	10.84
.12	6.68	10.08	7.72	10.96
.16	6.84	10.14	7.75	10.90
.20	6.96	10.16	7.70	10.72
.24	7.06	10.10	7.53	10.42
.28	7.10	9.96	7.33	10.04
.32	7.06	9.70	7.02	9.58
.36	7.02	9.43	6.60	9.25
.40	6.92	9.23	6.20	9.14
.44	6.82	9.08	5.87	9.27
.48	6.77	9.00	5.73	9.66
.50	6.75	8.97	5.71	9.92
.52	6.77	9.00	5.82	10.17
.56	6.88	9.14	6.20	10.58
.60	7.02	9.30	6.68	10.82
.64	7.13	9.53	7.07	10.85
.68	7.22	9.80	7.40	10.72
.72	7.24	9.97	7.66	10.43
.76	7.24	10.07	7.78	10.00
.80	7.17	10.14	7.85	9.73
.84	7.06	10.12	7.78	9.64
.88	6.94	10.10	7.61	9.68
.92	6.78	10.02	7.34	9.74
.96	6.62	9.90	7.20	9.87
1.00	6.42	9.80	7.13	10.16

This record on the telegraph paper also gives the time of each revolution to .002 of a second.

In the case of the Lowell engine, 11 consecutive revolutions each required the following time:

Number of Revolutions.	Time in seconds.
1,	4.566
2,	4.512
3,	4.579
4,	4.500
5,	4.500
6,	4.555
7,	4.426
8,	4.504
9,	4.534
10,	4.522
11,	4.576

In referring to this matter I make no comparison at all with the delicacy of the apparatus described by Mr. Eckart, but merely brought it to your attention because analogous results have been obtained by a less expensive apparatus which satisfactorily served its purpose.

Added since the Meeting.

In replying to Mr. Woodbury's questions, I will say that the length of drum is twelve inches, and but ten inches of that length was used for the curve traced when the stroke of the pump was ten feet. A much longer drum can be substituted if desired, but that length was found ample and reliable in recording the piston velocity of a pump-engine at eighty feet per minute, and also that of a hoisting engine with piston speed of 1400 feet per minute.

I do not understand from the description of Mr. Woodbury's instrument, and the manner in which he applied it, how he is to get analogous results, for there are no fly-wheels or rotating shafts about a Cornish or Davy Differential Engine, or pumps by which the telegraph paper and pulley he describes could be driven, and I have found from experience that if a reciprocating movement is given by a piston or a pump rod to a drum, or sliding frame, any equal time marks, made either by pencil or spark dots upon the recording paper, merge into a continuous line or become indistinct near the end of stroke, and further, as there can be no movement of the recording paper at the end of stroke there can be no record of the duration of pause, should the pumps or engines make one.

The element of cost, as Mr. Woodbury states, is against the instrument, but the results obtained from its use, however, are certainly very accurate, and leave no part of the piston motion undetermined.

W. R. E.

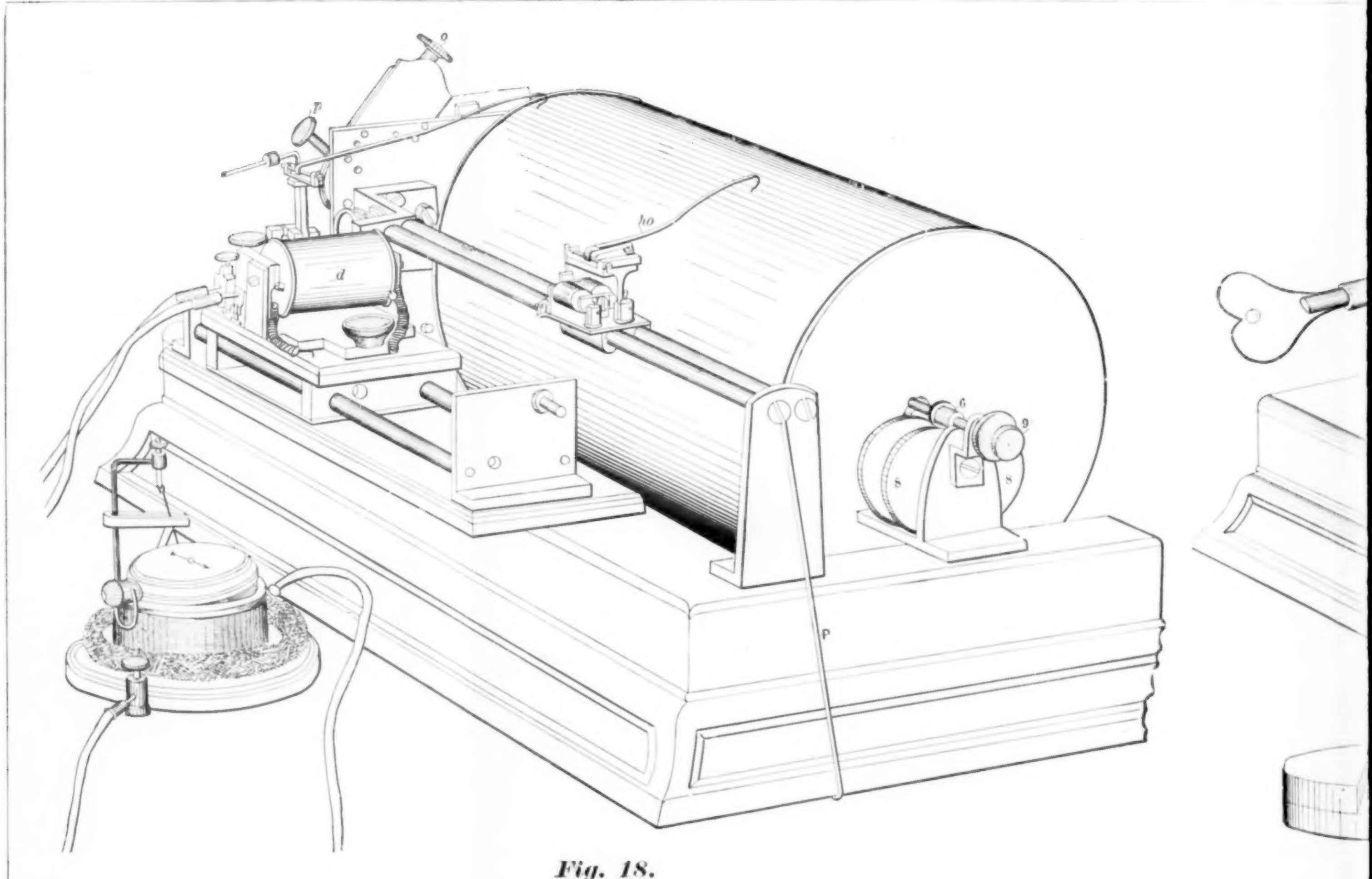
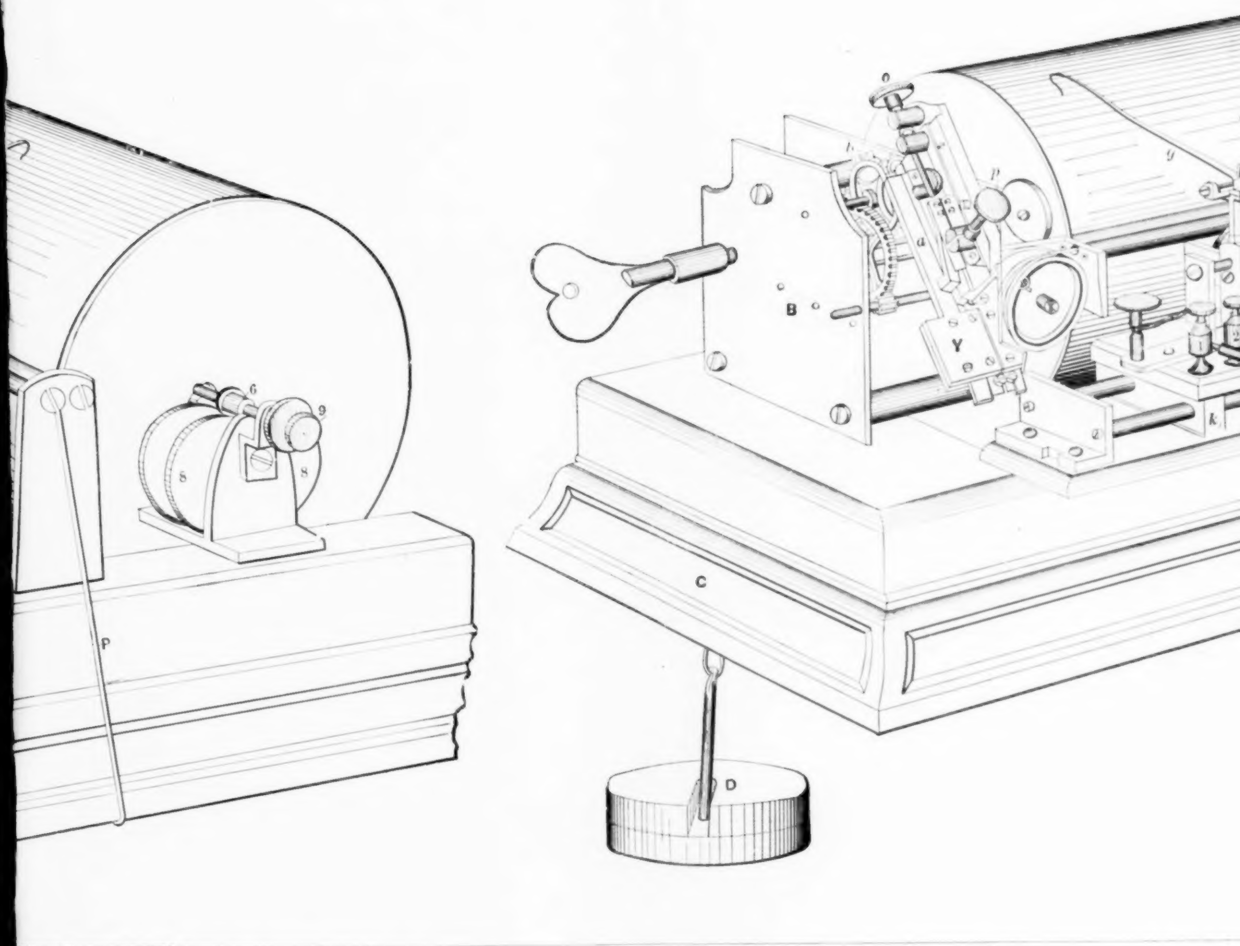


Fig. 18.


B
Y
C
D
P

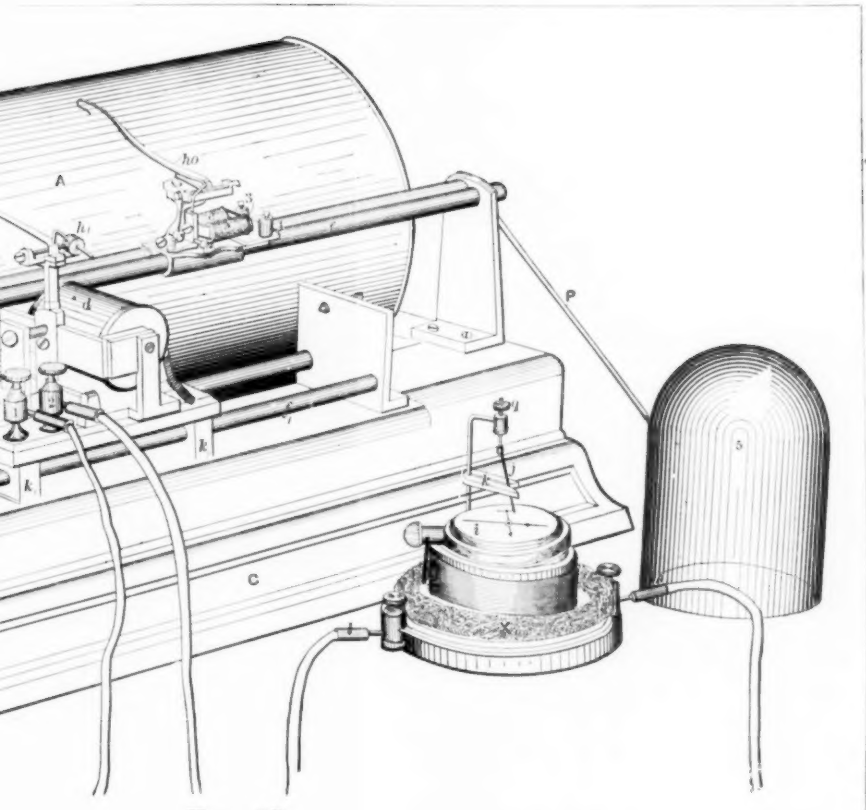


Fig. 19.

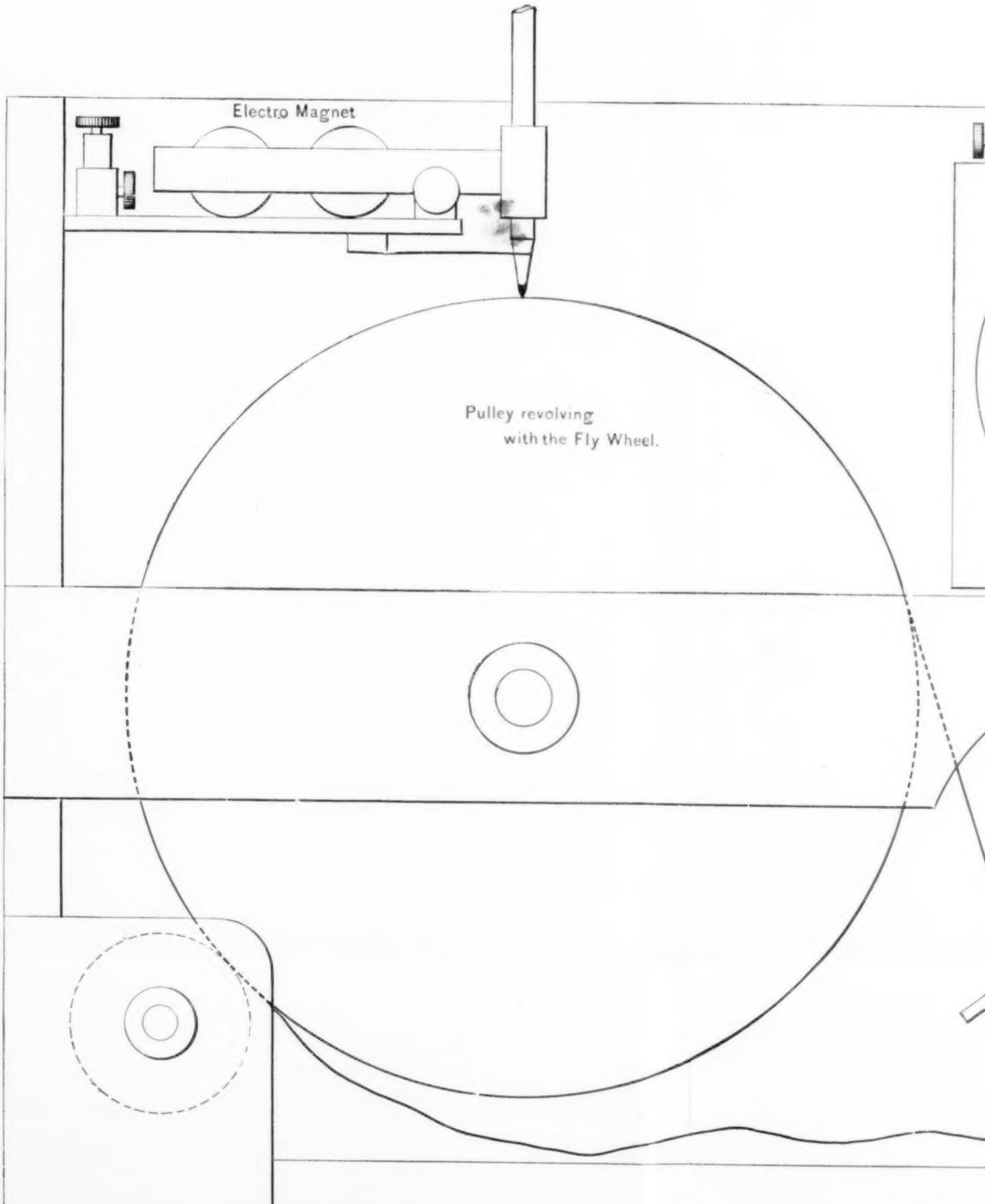
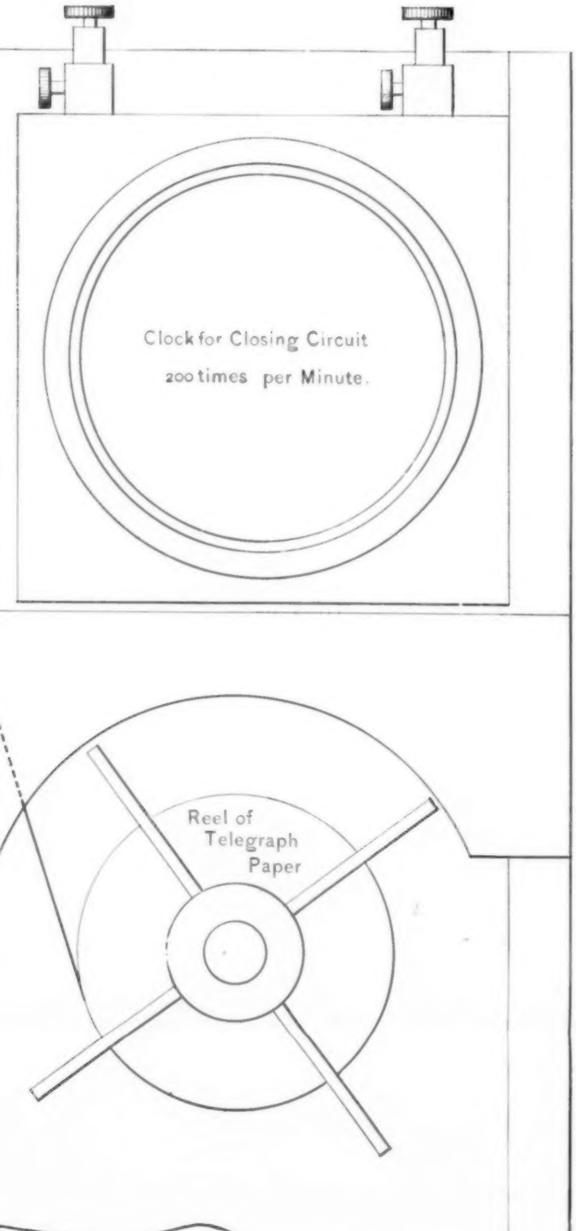
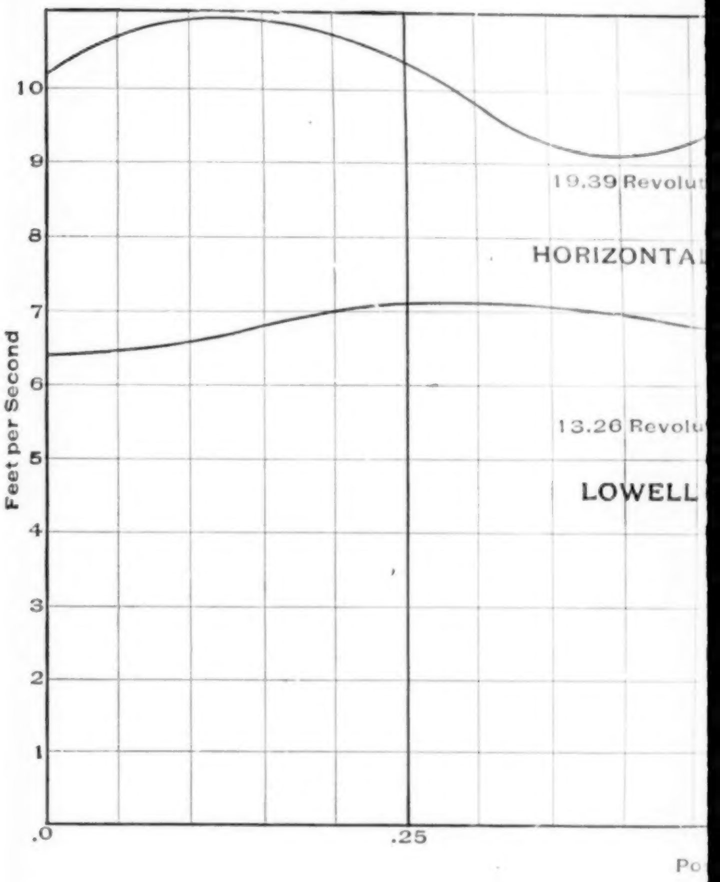
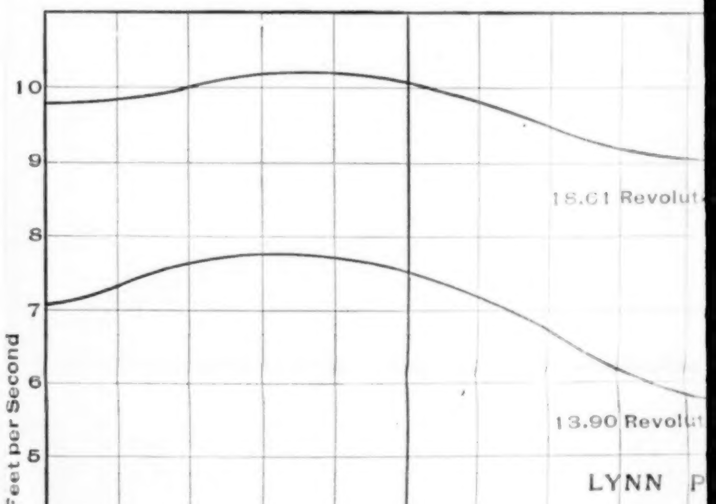
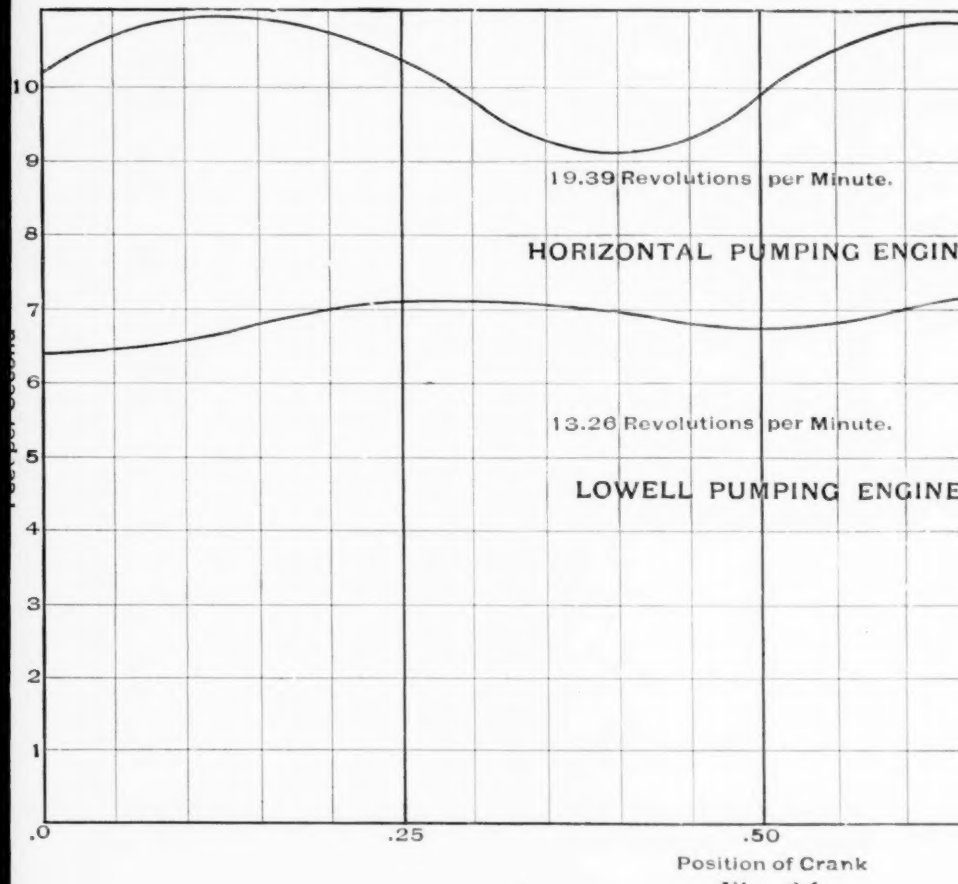


Fig. 20.


Clock for Closing Circuit
200 times per Minute.
Reel of
Telegraph
Paper

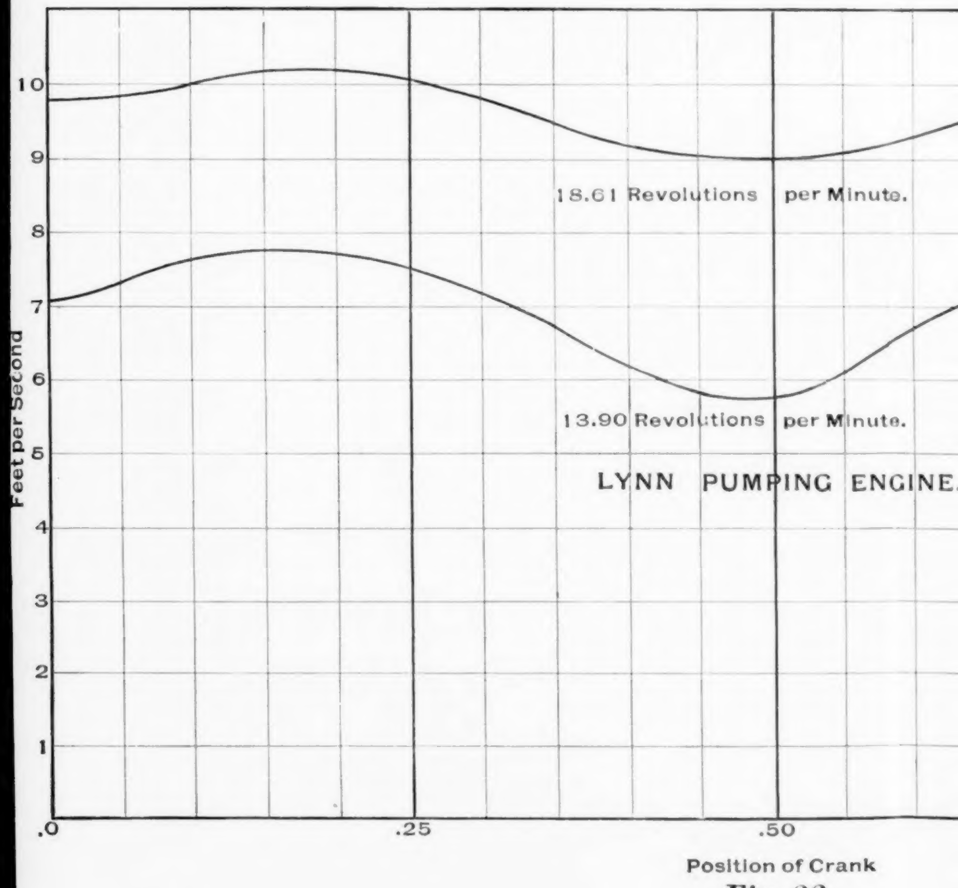

10
9
8
7
6
5
4
3
2
1
Feet per Second
.0
.25
19.39 Revolu
HORIZONTA
13.26 Revolu
LOWELL
Po


10
9
8
7
6
5
4
3
2
1
Feet per Second
.0
.25
18.61 Revolut
13.90 Revolu
LYNN P
Pos



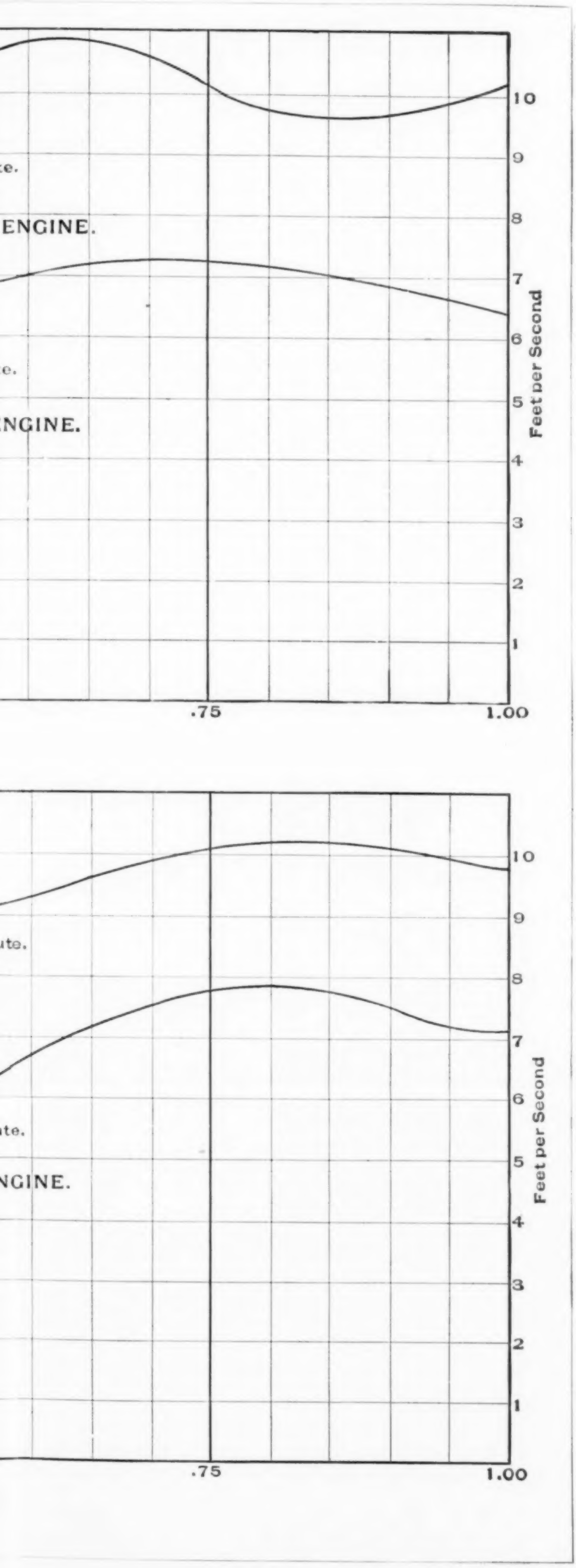
Feet per Second
10
9
8
7
6
5
4
3
2
1
.0
.25
.50
19.39 Revolutions per Minute.
HORIZONTAL PUMPING ENGIN
13.26 Revolutions per Minute.
LOWELL PUMPING ENGINE
Position of Crank

Fig. 21.



Feet per Second
10
9
8
7
6
5
4
3
2
1
.0
.25
.50
18.61 Revolutions per Minute.
13.90 Revolutions per Minute.
LYNN PUMPING ENGINE.
Position of Crank

Fig. 22.


ENGINE.
ENGINE.
Feet per Second
.75
1.00
ENGINE.
Feet per Second
.75
1.00

LXVII.

BUILT-UP WORK IN ENGINE CONSTRUCTION.

BY

HORACE SEE, PHILADELPHIA, PA.

THIS paper is intended to treat in as general and brief a way as possible of some of the advantages resulting from the use of built-up work in engine construction.

It will be desirable for you, before proceeding farther, to understand what is meant by the term "built-up" as applied to the subject under consideration. We mean a structure formed by the union of several simple members, these members or pieces being such as can be most conveniently, quickly, and economically made to give the necessary strength. Some object to this form of construction from mistaken ideas of economy, others from a false interpretation of beauty, but the largest class from extreme conservatism.

The advantages can be better understood by considering how a few of the forgings and castings, shown in the accompanying illustrations, entering into the construction of a compound marine propeller engine, are made.*

The following extract from a letter in *Engineering* of August 19th, 1881, strikes the keynote of the subject: "The fact will doubtless have its influence for all time coming, when the shafts for gigantic steamers are to be ordered, as it is absolutely impossible to insure that a forging shall be perfectly sound and destitute of flaws if, when it leaves the hammer, it is such an immense and ponderous mass as to weigh fully thirty tons, as did the one fitted into the 'Servia,' being eventually finished, however, at about eighteen tons in weight. All such shafts in future will doubtless be built."

The same argument applies to the solid forked connecting-rod, which requires about 50 per cent. of its weight to be taken off after leaving the hammer, with the attendant risk of not discovering the flaw until near the completion of the work. The impossibility of insuring soundness in forgings which require to have

* See note (*a*) appended.

from forty to fifty per cent. of their weight taken off after leaving the hammer, to bring them to the proper finished shape, should certainly cause the abandonment of a practice with so much uncertainty hanging over it, and lead to the adoption of one where the hammer can fashion each piece to nearly the required shape, where but a small portion of the rough material has to be removed, and where the risks are a great deal less. All of these requirements are met by the built-up system, which has also the additional advantage of furnishing to the forge such shapes as can be more easily made with the fibres of the material running in the proper direction.*

With castings, the evils resulting from crowding too much into one piece are of an analogous character. We will take a bed-plate to illustrate this. Two patterns, each consisting of one fore-and-aft and two athwartship members, have to be made, and the mould for each built up in loam. It is quite likely that the moulding of one will have to follow the other on account of a limited amount of room in the foundry, either on the floor or in the ovens. In the machine-shop the largest planing-machine is called into play, and that, quite possibly, not able to plane more than one piece at a time. Each piece will also have to be set twice.

Here the evil is not so much from the weakness of the structure as from the adoption of a slow and expensive system. This system will doubtless have to give place to the built-up, by making each member of the bed separate, where but one pattern is required for the athwartship and another for the fore-and-aft pieces. This subdivision also allows you to make castings in green sand. All of the athwartship pieces can be planed together at one setting as well as the fore-and-aft one, and on a smaller planer than in the other system.

This subject could be elaborated, but I think enough has been said to call attention to and furnish food for reflection upon a very important part of steam-engine construction.

Discussion.

Mr. Kent: In regard to this paper which has just been read, a gentleman here, who studied steam engineering under Rankine, and who had some experience in the shipyards of the Clyde,

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* See note (*b*) appended.

said that marine engineering was going to reach a limit soon in regard to cranks and crank-pins and crank-shafts. The paper before us I think points out one possible line of development, that is built-up pieces instead of solid pieces.

MR. SEE: There is one thing which results from this built-up system worthy of notice. In the construction of the crank-shaft, for instance, under this system, one or more kinds of material can be employed—either iron entirely, or iron in one part and steel in another.

MR. KENT: I suggest two things. Use steel in place of iron, and go as far away as possible from the ordinary hammer, using the hydraulic press. Professor Thurston will probably recollect a sample sent to Hoboken, showing the effect on a small ball of alloy about three-quarters of an inch in diameter, which had been pounded until it had grown about two inches in diameter. I am told by some very good hammermen, that it is possible by hammering a little on the surface of a forging to develop any flaw that exists there into a very large hole.

MR. SEE: I will state here that the crank-shaft of the "Servia," made to replace the one condemned, was built up and made entirely of steel by Mr. Vickers, the distinguished steel manufacturer of England.

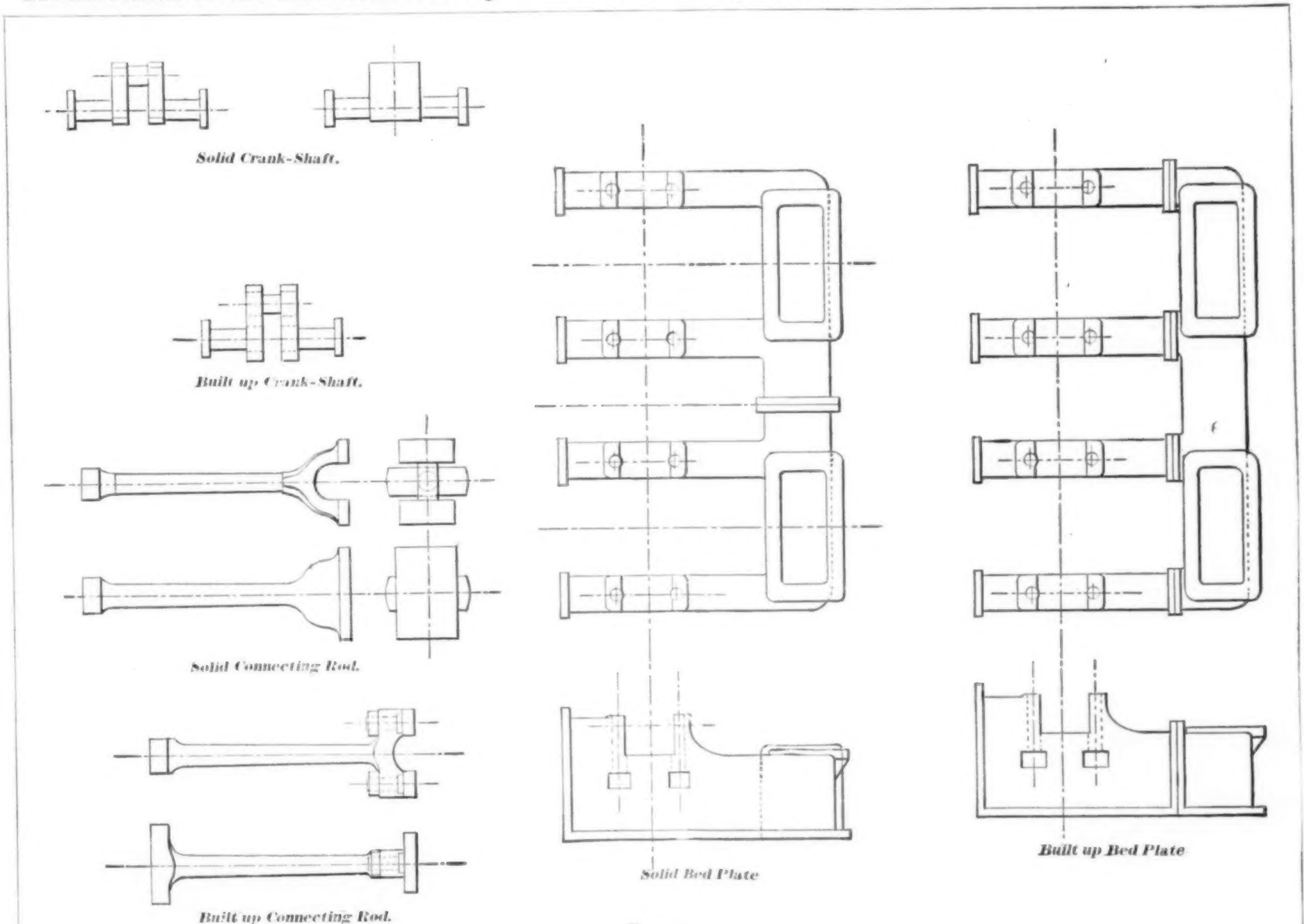
PROFESSOR THURSTON: I do not know precisely what is the phenomenon that occurs in that enlargement of parts under a light hammering. But I know that I have seen large shafts break to pieces under a light hammer. If there is a weak weld anywhere, or a broken weld, a light hammering simply results in the breaking of the shaft to pieces. I have seen shafts built under a light hammer in which you could force a wire along the axis for, I suppose, two or three feet. But I have no doubt, as Mr. Kent has suggested, that ultimately we will come to the use either of very heavy hammers for this class of works or preferably of the hydraulic press. My own impression is that the hydraulic press will be used. But I think that the Whitworth system will likely take the place of that. So that the direction of improvements in construction seems to me the securing of the right kind of metal, which is the right kind of steel. I was talking to a gentleman a few days ago, who was making some designs for pieces of heavy steel. I found that he had such sufficient confidence in a method of hardening to adapt his designs to the use of such a metal, a steel which

could be hardened in masses of eight, nine, and ten inches thickness. I have no idea how such a thing can be done, but I have no doubt that the time will come when a way will be found to do it. I have no question that some kind of steel will be the material we are to use, and that it will be put in shape by some form of hydraulic pressure, if it is done in the plastic state, or more likely by casting in form. My own impression has been for a long time that the Whitworth method, as now adopted by Whitworth himself, will be before very many years the usual method in the construction of these large shafts. The material being found, that method of working being adopted, this system of building up, which has been practiced more or less ever since I can remember, the building up of pieces, will be practiced wherever we have working facilities sufficient; and I see no reason to anticipate that any limit is to be found—that is at any early period—either to the size of parts, or the magnitude of machinery, or the power. I myself have no doubt that we shall build steamers twice as large as the "Great Eastern" without especial difficulty.

Added since the Meeting.

(*a*) There is shown, in Fig. 23, first, a solid crank-shaft as it appears when it leaves the hammer and after it has been finished. Then a built-up shaft when completed, made out of five separate pieces, that is, two shafts, two cranks, and one pin. Second, a solid connecting-rod as it appears when it leaves the hammer and after it has been finished. Then a built-up rod when completed, consisting of the rod proper with a T-head forged on at each end, and two T-headed bolts and nuts let into and secured to opposite sides of cross-head end of rod. And last, a solid bed-plate consisting of two complex and a built-up one of five simple members.

(*b*) A case lately occurred where it was necessary to replace a forked connecting-rod on a 1600 indicated horse-power engine. The condemned rod was of the solid type, and took to forge and finish, working ordinary time, sixty days. It was also the second forging made, the first one being found defective after a great portion of the machine work had been expended upon it. The new rod was built-up. The time taken from the date of order until finished complete with boxes bolted on, working day and night, was fourteen days. This saving of time was undoubtedly due to the simple form of the forgings, with the accompanying advantage of being able to divide the machine work amongst a number of tools, each working at the same time on its special piece. On a solid rod but one tool could work at a time, with the risk of not discovering a flaw until the last was engaged on it.



Solid Crank-Shaft.
Built up Crank-Shaft.
Solid Connecting Rod.
Built up Connecting Rod.
Solid Bed Plate
Built up Bed Plate

FIG. 23.

LXVIII.

AN ESSAY ON MECHANICS AND THE PROGRESS OF MECHANICAL SCIENCE—1824 *TO* 1882.

BY

FREDERICK FRALEY, LL.D., ONE OF THE ORIGINAL MEMBERS OF THE FRANKLIN INSTITUTE, AND PRESIDENT OF THE AMERICAN PHILOSOPHICAL SOCIETY.

With an Introduction by Coleman Sellers, M.E., Passed Vice-President of the American Society of Mechanical Engineers.

INTRODUCTORY.

WHEN it was proposed to hold a meeting of the American Society of Mechanical Engineers in the lecture-room of the Franklin Institute in Philadelphia, President Thurston suggested the desirability of a paper on the part played by the Franklin Institute in the progress of the mechanic arts in America, and he so advised the Local Committee. It happens that the present Treasurer of the Franklin Institute was one of those who organized the Society in the year 1824, and he has been not only a member ever since, but he has at almost all times been engaged in the management of the institution. It is natural to turn to one who has taken part in the active work of the Institute for fifty-eight years for information, so it comes that the writer asked his friend, Frederick Fraley, LL.D., to prepare the paper herewith presented. The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, has, through its more than half a century of existence, done much to earn its full title. While mechanic institutes started at the same time have long since passed out of existence, this Institute, founded on the broad basis of uniting all who are to give and obtain instruction, has grown and prospered. Its prosperity, and the work it has done, afford a useful lesson. It has never confined its membership to mechanics only, but while its constitution provides that its Board of Management shall hold a majority of manufacturers, it draws to itself all who are in any way interested in the progress of the Mechanic Arts, and this bringing together of men of varied interests on the common ground of seeking for information, has had the best possible result. Mr. Fraley has repeatedly told the

writer that he owes to the Franklin Institute the greater part of his education, and much of his success in life. In asking for this contribution to the history of a scientific society, it is hoped that the information given may be of use, not only to kindred societies, but even to one that is more limited in its range of membership than is the case with the Franklin Institute.

ESSAY.

FREDERICK FRALEY, LL.D.

I have been a member of the Franklin Institute since its organization in 1824, and this is the only right I have to present this paper for your present session.

When I recall my early remembrance of the mechanic arts in this city in the days of my youth, and compare them with what I see around me now, it is difficult to realize the change or to make any satisfactory comparisons. What was true of the condition of mechanical science in this city at the beginning of the present century was more so of every other part of the United States, and comparatively so, of the continent of Europe and of the island of Great Britain. The active inventive genius of the English and French people in the latter part of the 18th century was beginning to develop the germs of the great machines that have since been perfected, and have, it may almost be said, revolutionized the world. The laws of motion and the application of the mechanical powers had become to some extent known, and chemistry was rising in importance and aiding in carrying on the processes which were to subdue the rude natural materials which were to supply the mechanic with the means for carrying on his labors.

What was needed was the establishment of some kind of school that should bring together intelligent men of different professions and occupations, and by mutual support and study increase the amount of useful knowledge, and divide and distribute it to form new combinations and to make the growing wealth of such acquisitions available for the common good. It was for these ends that the Institute was founded, and its history truly records the growth, advancement and present state of mechanical science in the world. As it was the first really educational mechanics' association in the United States, it has continued to hold its rank as "*primus inter pares*."

Let us consider for a moment with what we had to deal in its origin. There were a few small and isolated workshops in which mechanical trades were carried on with rude and imperfect tools, and perfection depended more on the strength and skill of the hand of the artisan and on the acuteness of his eye, than on any clear mental perception of what he was doing or that the doing of it could be reduced to anything approaching scientific rules.

I recollect my visits to some of the well-known workshops of those days, and have seen Patrick Lyon striking vigorous blows on his anvil, Oliver Evans in his foundry, Jacob Perkins in his fire-engine manufactory, and the Messrs. Sellers in their then wonder-working wire works, turning out the marvellous hand and machine cards. It was indeed a great privilege to be permitted to visit those establishments, for they were the pride of their proprietors, and were not to be entered by all with impunity.

But with the establishment of the Institute came a new phase of these things. There had been for some years a sort of mechanics' club, which zealously guarded additions to its membership, and was so much attached to ancient mysteries, that it mercilessly blackballed all who attempted entrance by the shibboleth of modern ideas.

So it happened that Samuel V. Merrick was excluded from this venerable, close guild, and he resolved to form an institution on a more liberal basis and with broader views, and he joined to himself a few congenial spirits, who went manfully to work and called a public meeting of Philadelphia citizens, which was largely attended, and which enthusiastically adopted the plans of the founders, and gave us the great institution in whose Hall you are holding your present meeting.

True it is that Benjamin Franklin founded in Philadelphia, in the year 1743, the American Philosophical Society for the promotion of useful knowledge, but mechanical knowledge in that day did not hold the place it now does.

While Franklin followed a mechanical trade and did much handicraft work to make his printing attractive and profitable, he soared to higher heights and became philosopher, statesman and political economist, by which he earned his great and glorious name.

Philadelphia has always been distinguished for the beauty and excellence of its mechanical productions.

In the earlier part of the present century she was the point of attraction for purchasers from all parts of the United States.

It was therefore eminently fitting that a great mechanics' educational institution should be established in that city.

The plans for it were comprehensive, and struck down to the very roots of what was needed.

It took hold of the grown and skilful men of all trades, blended them with merchants, lawyers and scientists, put them all in personal and friendly contact for the communication and diffusion of all they knew, and then made provision for the education of the young in a high school, to be characterized by the teaching of what would be useful in practical life.

It established the first regular school in the United States for instruction in mechanical drawing, and has kept it in successful operation for more than fifty years. In the first year of its existence it had courses of lectures on mechanics, chemistry, archtecture, natural philosophy, and volunteer lectures on particular arts and trades. These lectures were attended by numerous classes, and made a great impression on the public, which increased the power and promoted the success of the Institute. This success gave it courage to hold an exhibition of American manufactures, the first held in the United States; and the specimens of American skill then presented were numerous, well made, and indicated a good basis on which future progress and perfection could be built up. Such exhibitions have been continued at convenient intervals, and have marked the march onward of mechanical skill. By the division of the leading members into standing committees on all the principal objects of the Institute, and by the regular meetings, the whole machinery of instruction was put in motion, and the results were soon apparent. It gathered a valuable library, and cabinets of models, minerals, and manufactured products, and thus soon became an Institute of Technology of the first rank, and that rank it continues to maintain at this day. It seems to be like the fable of the eagle continually renewing its youth, and as the old veterans have fallen from the ranks, the young and vigorous have filled up vacant places with enlarged knowledge and fired with the same confidence and hope.

Another aid given by the Institute to the development of mechanical science is found in its Journal. This publication has been continued monthly for more than half a century. It

contains a full *résumé* of American patents up to the period when the Patent Office commenced the publication of its reports. It contains, besides, many original essays and copious republications of articles on mechanics from foreign journals. By exchanges, it has largely contributed to build up the library, which has now a large store of wealth and technological knowledge.

In the way of original research the Institute can point with pride to its investigations of the value of water as a motive power; of the causes of explosion of steam boilers, of the strength of materials, of dynamo-electric machines, and to its examinations and reports upon many hundreds of new inventions.

These have brought into permanent notice many of the active members, who unselfishly devoted themselves to the elucidation and dissemination of the great truths which adorn the fields in which they labored. To name them all would be difficult indeed, for their number is not small. Prominent among them, however, are Samuel V. Merrick, William H. Keating, Robert M. Patterson, Matthias W. Baldwin, Rufus Tyler, Benjamin Reeves, Isaiah Lukens, Franklin Peale, Asa Whitney, John C. Cresson, William Sellers, Joseph Saxton. One of the early chiefs was Alexander Dallas Bache, who closed his life of devotion to science as Superintendent of the United States Coast Survey, a work which gave full play to the highest forms of accurate and useful applications of mathematical and mechanical knowledge.

In this connection, also, I must strive to pay just tribute to the merits and zeal of its professors, among whom we find in its early days, R. M. Patterson, William H. Keating, William Strickland, Franklin Bache, John K. Mitchell, Walter R. Johnson, John C. Cresson, James B. Rogers, and John F. Frazer. Their successors are numerous and worthy, and they in the present days are upholding the honor and sustaining the reputation of this mother of mechanical institutes of our country. As she was the first of these really educational institutions, the model which she presented has been closely followed, and the benefits which she gave to the mechanics of Philadelphia are now largely shared by the craftsmen in all parts of our widely extended territories, by the labors which such kindred institutions have fully and freely bestowed.

My object in the preparation of this paper was to attempt to show by the history of the Institute, some illustration of the progress of mechanical science for the last sixty years, and to show by the gleanings I have made from this vast field, amid the active labors of a different line of life, the impressions made upon my mind by the truly marvellous triumphs of mechanical skill, which have claimed my admiration and remembrance. If I shall add an hour of pleasure to your meeting I shall be amply repaid for its preparation.

I cannot close it, however, without attempting to bring before you, in contrast, what I saw of machinery and its progress in my youth, and what I see now. I shall refer first to the supply of water to the city of Philadelphia.

Then she was just emerging from the use of wells and hand-pumps, and the rude steam engines placed near the Schuylkill River at Chestnut Street and at the base of the marble building in the Centre Square at Market and Broad Streets; and the modest basin eighty feet at its summit, and sixty feet in diameter, were the wonder and boast of the citizens. The pipes for the distribution of the water were wooden logs bored by hand, and it was not until after the establishment of the Institute that iron pipes were cast in this country. A few had been imported from England, and this fact became a political war-cry, and nearly revolutionized the city government. About the year 1822 the water-works were established at Fairmount, a transfer of the steam-power having previously been made to that point, a large Boulton & Watt engine having taken the place of the original engines. The Boulton & Watt engine was a beautiful piece of work, and marked a well-defined phase in mechanical engineering. For a short time by its side worked a high-pressure engine of great simplicity and with few parts, invented and constructed by Oliver Evans, the great American mechanic, who is probably the inventor of the use of steam under high pressure, and who deserves a high place in the pantheon of inventors. Recollect that then no other large city in the United States was supplied with water by machinery, and that the representatives of city corporations came to study and imitate our example. Now every large city boasts of its water-supply arrangements, and the steam and water powers exhibit the perfection which study and experience give. Compare the locomotive engine of the present day with the embryo of

Oliver Evans; or the machine of Blenkinsop, or the English machines of Stephenson, or the first one of Baldwin, with those which are now daily turned out of the hundreds of the great shops of the world, and notably those of our own country, and you will again realize the progress of your special science.

Look at the manifestations of the same progress from the rude spinning jennies and mules of Arkwright and Crompton, to the contents of a modern cotton or woollen mill, and marvel at the mechanical fingers which spin and weave the massive sail-cloth or carpet, and the gossamers which clothe the queens of kingdoms and of fashion.

Look at the machines and tools of precision, and see how they have contributed to bring about so much perfection.

In this connection, also, the introduction of standard sizes and uniformity in the several parts of machines have tended to great economy and practical usefulness.

How much has been gained by the adoption of the United States standard for screw threads, for which we are indebted in a large degree to the ingenuity and experience of Mr. William Sellers. The stand taken by the Institute to prevent a forced adoption of the French metric system has been of great use in guarding us from a violent and unnecessary revolution in the weights and measures of our country. These are so identified with all our measurements and the welfare and protection of society and property, that to disturb them seems to me to be as criminal as the burning of the great library at Alexandria.

Upon such a survey of the progress of mechanical science as it has fallen under my observation and study, I feel that the men of this century have well performed their duty, but they must keep their hands to the plough and not be content with what has been accomplished. They must cherish the spirit of brotherhood, be ready and willing to communicate and spread all useful knowledge. They must aid in keeping up the great educational institutions of the country, especially in their scientific and technical departments, and so give to the present and coming generations the advantages and accumulations of all the wealth of knowledge which has been obtained by the labors of genius and perseverance, and provide more abundantly for their increase.

LXIX.

AVERAGING MACHINES.

BY

W. S. AUCHINCLOSS, PHILADELPHIA, PA.

THE averaging machine is a device for determining the centre of gravity of a system of representative weights located at any desired distances from each other. These weights can represent dollars, tons, pounds, or merchandise, and the distances by which they are separated can represent the intervals of time between which purchases were made or the distances by which specific loads are separated. In the case of time intervals, the location of the common centre of gravity of the representative weights will determine the average time of purchase, while in the case of distance intervals the common centre of gravity will be located with regard to a common starting-point, or zero.

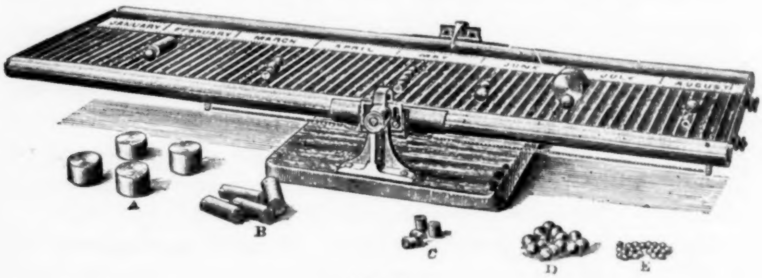


FIG. 24.

The first requisite of the problem is that, no matter what the position of the unloaded platform, with reference to its points of support, its equilibrium must be perfect. This is easily secured by supporting it on a saddle C, in which it freely slides, and equalizing the weight of the platform by counterweights F F^1, in hollow side-tubes. As the platform A is advanced in the direction No. 1, the counterweights F F^1 move with precisely the same speed in the opposite direction, and thus maintain the equilibrium. This isochronous action of the counterweights is secured by attaching their extremities to the platform A, through the medium of chains passing around four pulleys on the saddle C.

By means of this device the influence of the weight of the platform is entirely eliminated from the problem, which is reduced to that of simply determining the centre of gravity of a system of representative weights.

The weights, for convenience, are made of sizes to represent units, tens, hundreds, thousands, etc. The platform A has a suitable number of equidistant grooves, and the accompanying paper-scales are divided in harmony with the grooves, for the varying problems to be solved by the machine.

In Commercial Transactions involving time problems, the machine will readily solve one hundred accounts per hour.

In Civil Engineering it gives the average haul of excavations and embankments with great rapidity and unfailing accuracy.

In Mechanical Engineering the machine may be used for deter-

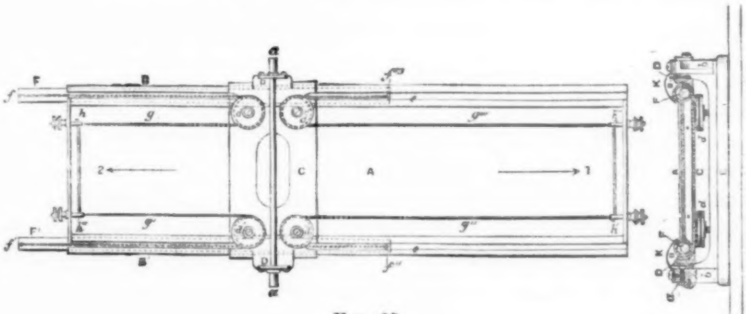


FIG. 25.

mining the location of the centre of gravity of engine, boilers, coals, cargo, etc., before placing same on a steamer; also for determining diameters of pulleys and speeds of shafting.

In Ship-building it will determine the centre of buoyancy for various water-lines; also location of centre of gravity of hull.

In Mercantile Exchanges it will determine the average price of any number of "futures."

The machine likewise solves all examples of arithmetical proportion.

Another form of this same device is shown in the cut, p. 222, which represents the endless chain method. This machine secures greater rapidity of action, and will solve 140 accounts per hour.

After the completion of each problem the endless chain is drawn along its platform and the weights drop upon an inclined

surface, along which they roll to a bar in front of the machine. This bar acts as a screen, and separates the larger from the

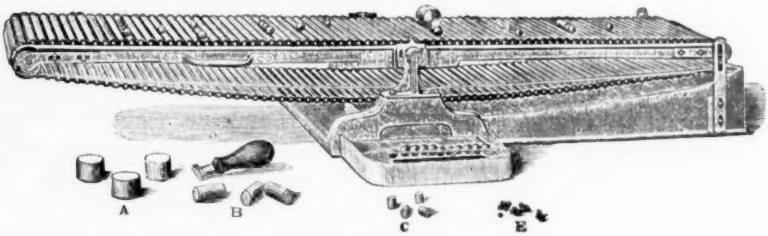


FIG. 26.

smaller weights, after which they are in readiness for the next problem.

Such a machine will work about six times as fast as an expert accountant, and with greater certainty as to the results attained.

DISCUSSION.

PROFESSOR THURSTON: This method has proved an exceedingly useful one in determining centres of gravity in naval architecture. One of the most experienced naval architects I have known in this country has used such a method for the last forty years, and he has built a tank of sufficient length, and in this long tank he places a model of the craft he proposes to build. Then he has a set of weights precisely as here, which represent one ton, ten tons, etc., and he places these upon his model just where he proposes to put engines, boiler, stores, cable, locker, etc., and he determines on the centre of gravity. This gentleman has been adopting that method, which is ruder than this, for a long time, and in preference to all calculations.

Added since the Meeting.

It will be observed that, although the naval architect referred to, secures a satisfactory location of the engines, boilers, stores, cables, locker, etc., his empirical method does *not*, in any sense of the term, locate or determine the common centre of gravity of the bodies, so that the centre becomes a known and definite point.

The averaging machine, however, *will* determine its location with *absolute* precision.

W. S. A.

LXX.

EXPANSION OF STEAM AND WATER WITHOUT TRANSFER OF HEAT.

BY

A. FABER DU FAUR, NEW YORK CITY.

FOR adiabatic expansion of steam and water the formula of Clausius (as given by Zeuner, in his *Waermetheorie* of 1860, page 114) is as follows:

$$\frac{m_2 r_2}{T_2} = \frac{m_1 r_1}{T_1} + Mc \text{ log. nat. } \frac{T_1}{T_2}. \quad \text{(I)}$$

where—

T_1 and T_2 = absolute temperatures at the beginning and end of expansion.

m_1 and m_2 = weight of steam at the beginning and end of expansion.

r_1 and r_2 = heat of evaporation at and from the temperature T_1 and T_2.

M = aggregate weight of steam and water.

c = specific heat of water.

For $M = 1$, that is, for the unit of weight of mixed steam and water we get

$$m_2 = m_1 \frac{r_1 T_2}{T_1 r_2} + \frac{T_2}{r_2} c \text{ log. nat. } \frac{T_1}{T_2}. \quad \text{(II)}$$

This is also the equation given in Rankine's *Steam-Engine*, London, 1859, page 385, formula (5), using units of heat in place of foot-pounds, J, as stated on page 383, being the dynamical value of the specific heat of water.

The equation (1) is derived from the differential equation:

$$Mc \frac{dT}{T} + d\left(\frac{mr}{T}\right) = 0.$$

The value of c is not constant. Zeuner, page 98, formula (108), and page 88, gives:

$$c = 1.1 - \frac{30.456}{T} \text{ for Centigrade scale.}$$

By substituting this value into the differential equation, and taking the integral between T_1 and T_2, formula (II) becomes for Centigrade scale;

$$m_2 = \frac{T_2}{r_2} \left\{ 1.\ 1 \text{ log. nat. } \frac{T_1}{T_2} - 30.456 \left(\frac{1}{T_2} - \frac{1}{T_1} \right) \right\} + m_1 \frac{r_1 T_2}{r_2 T_1}. \qquad \text{(III)}$$

$$m_2 = A + m_1 B. \quad \text{(IV)}$$

where $$A = \frac{T_2}{r_2} \left\{ 1.\ 1 \text{ log. nat. } \frac{T_1}{T_2} - 30.456 \left(\frac{1}{T_2} - \frac{1}{T_1} \right) \right\}$$

and $B = \frac{r_1 T_2}{r_2 T_1}$.

From equation (III) the values of m_2 in the annexed table and diagram of curves have been calculated. The upper curve of the diagram beginning at $T_1 = 473$, and $m_1 = 1$, and ending at $T_2 = 293$, and $m_2 = 0.726588$, represents the expansion of originally dry steam between 473° and 293°; the lower curve, beginning with $T_1 = 473$ and $m_1 = 0$, represents the expansion of water between 473° and 293°. From equations (III) and (IV) it follows that by dividing the vertical distances between the two curves into equal parts, and connecting the corresponding points of division, new curves are obtained which are equally correct; it also follows that the divisions may be continued above the upper curve up to 1 and beneath the lower curve to 0, as in the diagram.

By the use of steam tables the pressure and volume of the steam at the various temperatures is readily obtained, also the heat contained in the unit of weight of steam, so that the heat contained in the mixture of steam and water, indicated by the curves, is easily calculated.

From the values of m_1 and m_2 in the annexed table, I have calculated the exponent or index i in the formula, $\frac{v_2}{v} = \left(\frac{p_1}{p_2}\right)^i$ as follows:

$m =$	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0
Between 473 and 293,	1.120	1.112	1.103	1.093	1.081	1.066	1.046	1.018	0.976	0.904	0.681
Between 473 and 273,	1.138	1.128	1.102	1.096	1.078	1.053	1.024	0.975	0.912	0.798	0.485

Theoretically the annexed curves show the final conditions of mixed steam and water acting against a piston and expanding between any two temperatures, no matter what the intermediate stages may be, provided that whatever heat the steam may have imparted to its surroundings during part of its action, shall have been restored at the end.

Practically the operation of steam is as follows: The initial condition of steam being represented by A in the annexed diagram (Fig. 27), and the theoretical changes of its condition during expansion by the curve A B, the cool surface of the cylinder will, during admission, change the initial condition by condensation to A_1, at the same time raising the temperature of the metal; the heat thus lost will be partly restored during expansion, so that the condition of the expanding steam will not be represented by the curve A_1 B_1, but by a curve terminating above it.

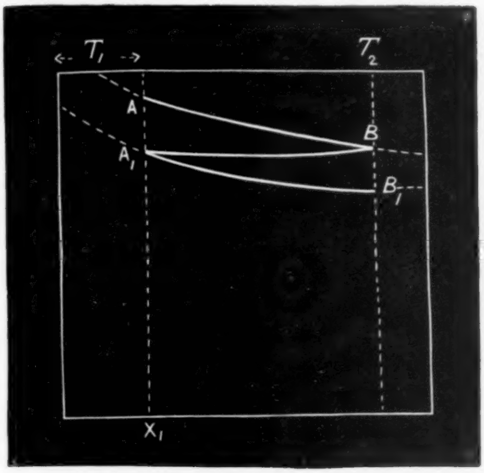


FIG. 27.

If all the heat were restored, then B would represent the final condition of steam, and the energy exerted would be the same as the one calculated from the theoretical curve A B, although the change of its condition is represented by A A_1 B, or by any other line connecting the points A and B.

The total energy exerted by 1 pound of water and steam, during admission and expansion, is then computed as follows:

Heat supplied $= c + m_1 r_1$

Heat rejected . . . . $= c_1 + m_2 \left(r_2 - \frac{p_2 u_2}{J}\right)$

Heat transformed into energy $= c - c_1 + m_1 r_1 - m_2 \left(r_2 - \frac{p_2 u_2}{J}\right)$

Where:

P_2 = pressure corresponding to final temperature T_2.

u_2 = volume corresponding to final temperature T_2.

J = mechanical equivalent of heat.

c and c_1 = heat units in one pound of water.

It is seen that even if no heat be lost through the action of the surfaces of the cylinders, the alternate rise and fall of temperature of the surfaces will change the curve of expansion so that the calculated index will not apply even to adiabatic action, that is to say, to such action in the steam cylinder, where the total heat absorbed by the surfaces during admission, is restored without loss during expansion.

Practically, however, we have no absolute adiabatic action, part of the heat being carried off mainly by the re-evaporation of water on the exhaust side, that is to say, the cylinder and piston will give up heat to the exhaust, which heat is not restored, but is discharged with the exhaust, and is additional to the rejected heat as theoretically determined. The quantity of heat thus lost must be deducted from the heat theoretically transformed into energy, to get the actual energy exerted.

The quantity of heat wasted with the exhaust, in addition to the rejected heat as theoretically determined, or as shown by the condition of mixed steam and water before the opening of the exhaust port, depends on various conditions, such as the surface of the metal exposed to the steam, the range of temperature, the time of one alternation, or the time required for one stroke ; probably also, to a great extent, the difference between the final temperature of expansion and that due to the back pressure.

We have a great array of special curves proving very little without complete, definite, and reliable data. Owing to the alternate receiving and emitting of heat by the surfaces of the cylinder, the adiabatic curve may take various shapes, but these shapes must be obtained by carefully prepared experiments, and not founded on assumptions or doubtful experience.

We have, also, experiments as to the condensation of steam during expansion, but so far they have not enabled us to calculate what is wanted, namely :

(1st.) The amount of heat transmitted to the exhaust per square foot of metal surface for various conditions.

(2d.) The heat lost per square foot by radiation or conduction.

(3d.) The heat transmitted per square foot by a steam jacket.

A series of experiments especially made for determining these

quantities, and such experiments alone, would enable us to determine the actual rejected heat, and the total energy exerted by steam under all circumstances. Theory shows us what is possible without loss; practical experiment must demonstrate what the loss is, and how it varies under different circumstances.

It surely is much easier, more logical, and more correct to arrive at a positive and conscientious result by adopting what theory dictates, and deducting the actual loss determined by careful experiment, than by attempting to bring crude experimental facts or vague and disconnected experience into a general though questionable rule, without regard to the theoretically possible.

Expansion of Steam and Water without Transfer of Heat.

Absolute Temp. Centig.	473°	453°	433°	413°	393°	373°	353°	333°	313°	293°
Pressure in Atmospheres.	15.38	9.929	6.120	3.576	1.962	1.	0.466	0.196	0.072	0.023
Weight of water per unit of mixed water and steam.	0.0	0.042207	0.080462	0.113731	0.143568	0.169740	0.192420	0.211750	0.227858	0.240818
	0.1	0.135075	0.166680	0.193692	0.217576	0.238128	0.255475	0.269741	0.281022	0.289395
	0.2	0.227943	0.252898	0.273654	0.291585	0.306516	0.318530	0.327731	0.334186	0.337972
	0.3	0.320811	0.339116	0.353615	0.365593	0.374904	0.381585	0.385721	0.387350	0.386549
	0.4	0.413679	0.425334	0.433577	0.439601	0.443292	0.444640	0.443712	0.440514	0.435126
	0.5	0.506547	0.511552	0.513538	0.513609	0.512680	0.507695	0.501703	0.493678	0.483703
	0.6	0.599415	0.597770	0.593499	0.587618	0.581068	0.570750	0.559693	0.546842	0.532280
	0.7	0.692283	0.683988	0.673461	0.661626	0.648456	0.633805	0.617683	0.600006	0.580857
	0.8	0.785151	0.770206	0.753422	0.735634	0.716844	0.696860	0.675674	0.653170	0.629434
	0.9	0.878019	0.856424	0.833384	0.809643	0.785232	0.759915	0.733664	0.706334	0.678011
	1.0	0.970887	0.942642	0.913450	0.883651	0.853620	0.822970	0.791655	0.759498	0.726588
Pressure lbs. per sq. inch.	225.8	145.8	89.7	52.5	28.8	14.7	6.86	2.09	1.06	0.33
Temperature Fahrenheit. (Ordinary Scale.)	392°	356°	320°	284°	248°	212°	176°	140°	104°	68°

Discussion.

Mr. Wolff: In presenting Mr. Du Faur's paper I feel that I have not been able to do it justice, from having just received it and that it is full of mathematics; but at the same time I have been so impressed with the work that Mr. Du Faur has accomplished that I have taken great pleasure in making the subject as clear as I could. Mr. Du Faur has taken the formulæ of Clausius and Rankine for the expansion of steam and water in a cylinder without transfer of heat, has made substitutions in these formulæ for different amounts of initial water and steam in the steam entering the cylinder, and has calculated the condensation for different ranges of expansion. He has thus determined the amount of condensation which takes place in a non-conducting cylinder, owing to the expansion of the steam alone, not owing to any transfer of heat from the steam to the cylinder and its return to the steam, considering the metal of the cylinder entirely as a non-conducting material. I think we all recognize the value of work of this kind. Mr. Du Faur has presented his results both in table and graphically, as you may perceive. We all know that there is a great amount of condensation taking place in a cylinder owing to the expansion of steam alone without transfer of heat, but without tables of this kind or graphical illustrations we are not apt to fully realize the exact amount. I therefore consider it the chief value of the work which Mr. Du Faur has accomplished, that we shall be able in any experiments that may be made in the future, to know at a glance how much condensation is owing to the work done in expanding the steam itself, for internal energy, and how much on the other hand is owing to conduction, radiation, and re-evaporation.

If I may be permitted to add a word to Mr. Du Faur's paper, I would like to say that I think we all recognize at the present time the necessity of determining the amount of condensation of steam in cylinders by experiment, and if I was not aware that such a number of committees had been appointed this evening to look into various matters, I, for one, should call upon our President to nominate a committee for this purpose. I think there is no work to which we could devote our energies with more satisfaction, that there is no work that we can do in the engineering profession to-day which is more seriously demanded

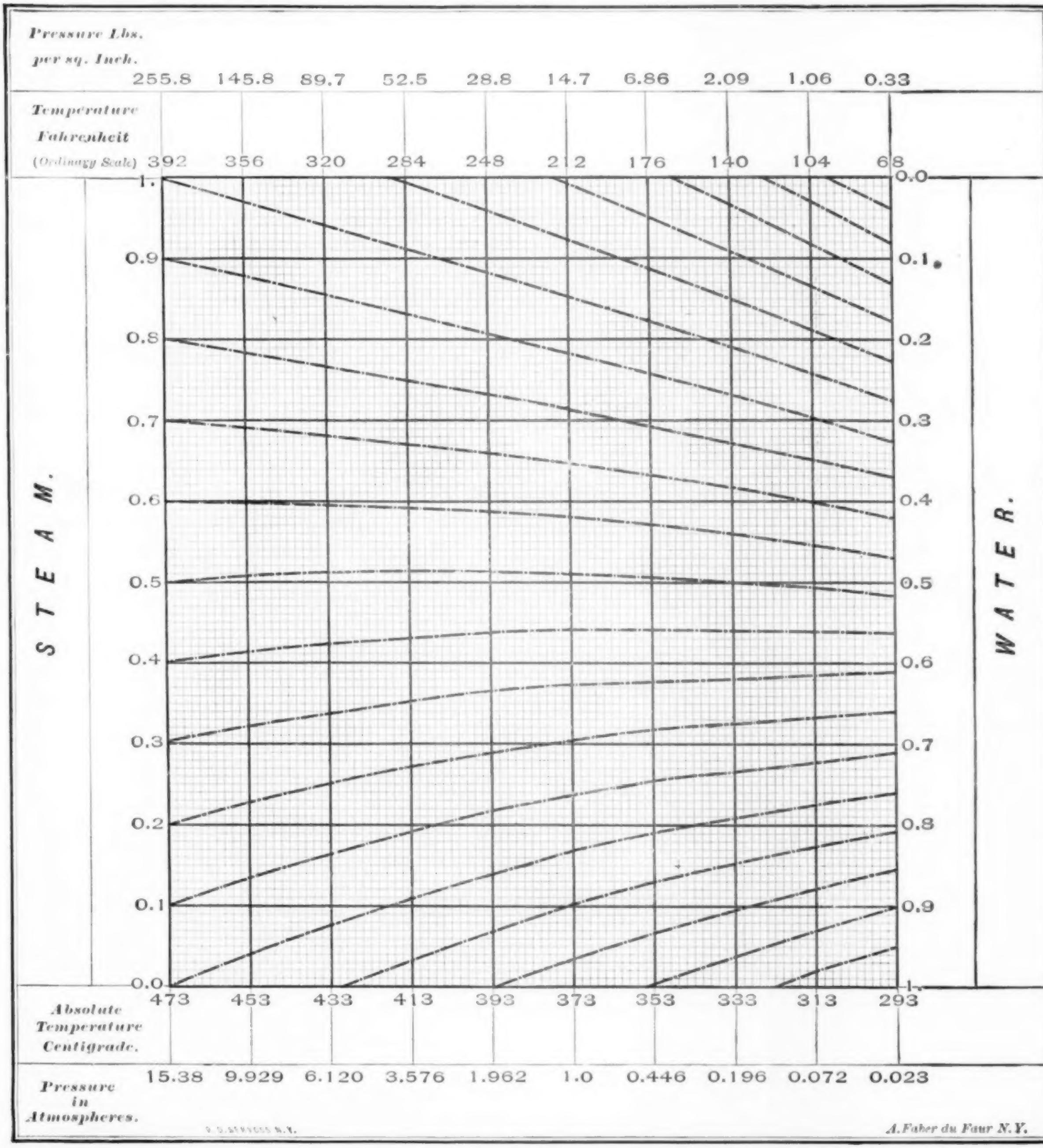
or which would gain for us a greater national reputation. To-day, the little experimental work that is being done in this direction is being done abroad by Hirn, Hallauer, and their collaborators; but until now their results have not been such as to produce definite rules. It might be said that Mr. Isherwood made experiments in this direction. Mr. Isherwood has made experiments which were very cautiously prepared and recorded, as any one who has carefully read his report will see. If any fault can be found with the experiments, it is that he did not determine the condition of the steam as it left the boiler. The mistake that Mr. Isherwood, however, apparently committed, was that the deductions which he made for a particular series of experiments, while correct for those experiments were made more general in their application than was warranted. On engines where the piston speed was not above 300 in any case, usually between 200 and 300, and where the revolutions were very low indeed, a great amount of condensation was found, and this he apparently concluded would be the amount of condensation in all engines. Now, in the *Journal of the Franklin Institute*, for February, 1879, Mr. Isherwood, in speaking of the performance of the engine of the "Mary Powell," which he calls a typical paddle-wheel engine, mentions that no condensation occurred in the cylinder; that evidently the steam consumption with the ratio of expansion used showed that there could be no condensation; hence we have on the one hand Mr. Isherwood a number of years ago making careful experiments where a great amount of condensation was shown, and in 1879, on the other hand, he records the case of a similar engine with no condensation at all. These latter experiments were, however, not made by Mr. Isherwood himself.

I have also looked carefully into the experiments of Mr. Hirn, and find that Mr. Hirn himself has come to no conclusion at all relative to the condensation of steam in cylinders at different ratios of expansion, but states that Mr. Hallauer, his co-worker, will present these results. Mr. Hallauer's paper has been published, and there again we have no definite results obtained. However, the work which they are doing there in France appears to be of the most careful character, is in the right direction, and ought ultimately to produce the desired correct results. Meanwhile, we have to a great extent to rely for knowledge in respect to condensation of steam in cylinders upon such general

information as experience will give us; but I think the information which experience gives us is in many ways very unsatisfactory, and therefore I heartily favor all that Mr. Du Faur says: that specially arranged experiments for this purpose, as to the effect of different conditions of speed, time of exposure, etc., which evidently enter into the practical question of condensation, should be carefully considered. It is only because the other committees have been appointed, and I recognize that the society has its hands full, that I do not now make a motion to that effect.

PROFESSOR THURSTON: This paper interests me very much, but I do not yet realize all that it contains. I should have to read the paper carefully to see what is there. It interests me to see how many minds are working in one direction, and how many people are recognizing the importance of this subject. We are absolutely at sea with regard to this whole matter. Perhaps I should hardly say that. We are so much at sea that we have no data, and we are uncertain as to our exact course. Even in the theoretical treatment we are a good deal at sea. The exponents that we use in the treatment of these assumed hyperbolic curves are not simply of uncertain magnitude, but it is certain that they do not represent exactly what they are intended to represent. I suppose that all engineers rely upon Zeuner's expression of the value of an exponent. But in looking over his works, you will find that it only approximates the mean value in a case where the value is constantly changing; a mean value as near as he can get it for a certain set of conditions. Those sets of conditions are rarely the same. And then again, assuming that the Zeuner exponent is nearly accurate for every-day work, you will find then that the conditions you meet in experimental work are very different from those assumed in our theoretical treatment, and that the exponent becomes something entirely different from that. I never yet found an indicator card in which the exponent was that given either by Rankine or Zeuner, or anybody else, so far as I know, who has treated that subject. All the indicator cards I have examined have given exponents, either substantially unity, within perhaps one-hundredth of unity, or considerably lower, while all of the exponents given by Zeuner's formula, if we take it within the range of ordinary practice, considerably exceed unity. Then again, after we have got a value for this exponent that suits the expansion curve, if we use that for a determination of the amount of heat likely to be consumed, we

find that we are entirely adrift when we compare that for results. When we go to experimenting to determine what the waste is, we find the experiment does not tell us. In the paper I presented yesterday morning, you will find I took approximate results, and in some cases I could not get any definite results at all, and the best I could get, were those Mr. Wolff has spoken of,—those of Isherwood on the condensing unjacketed engine. Isherwood, in the second volume of his "Researches," presents what seems to me about the average figures for the working of such engines. But on comparing his figures with his work, you will find that the condensation given there, is not the condensation that actually exists, but only an approximation, which he obtains by assuming that his measurement covers all condensation. So that in the best curve of efficiency that I could produce, I still could not reach the point that I wished to gain. I produced a curve which represents Isherwood's figures, but it does not represent actual facts. It is, I presume, fairly approximate, but it is not satisfactory; so that we stand to-day absolutely, so far as I know, without any one complete series of experiments of the kind we want. It is for that reason that the results given in my paper must be taken as entirely provisional, and the best I can hope to do there is to point out a method to be of use when we get such a result. The thing an engineer wants is just this class of experiments. The results must be properly collated, and the exact meaning of those results determined, the probable value of observed quantity ascertained, and probably we should find it even advisable to go into the domain of the astronomer, and determine errors by some of his methods, and after a large amount of work has been done, we can get something that will be of some real service to us. I presume no engineer that understands the matter at all would be at all satisfied with the result on any one class of engines so far as is known to-day. The presentation of a paper of this character, as I say, indicates that engineers are beginning to appreciate these facts, and when this is done for every class of engine running under every set of conditions, we can determine the exact behavior of steam, for every ratio of expansion that can be adopted in such engines, and we then will have a set of figures, a collection of facts, on which we can probably base a treatment that will be satisfactory, and till then we shall be to a very considerable extent in the dark. So far as I have been able to



Expansion of Steam and Water Without Transfer of Heat
Curves Showing Relative Proportions of Steam and Water.

FIG. 28.

ascertain, there is not in existence to-day a set of experiments that are of any very great value. There is no one complete set of experiments on any one of the class of steam-engines to-day in common use, and there are no experiments at all, of the kind we want, on the kind of engines we are most interested in; those that our colleagues are building at the south end of the town, those that you will find built by Worthington, or any of the builders of the class of pumping-engines that are coming into use constantly. We know next to nothing about the behavior of steam in the locomotive cylinders; and I want to emphasize my own views on this subject, so that I cannot by any possibility be misunderstood. I want to be understood as being thoroughly desirous of seeing this kind of work done, and do not want to be understood as being in the slightest degree inclined to prejudge or anticipate results.

Mr. Wolff: I think that the experience which we have as to condensation will enable us to settle some very important problems satisfactorily in practice; but, of course, what we are after are exact data. And I am glad to see that you take the same view as Mr. Faber Du Faur.

LXXI.

DESCRIPTION OF THE EDISON STEAM DYNAMO.

BY

T. A. EDISON, PH.D., NEW YORK CITY,

AND

CHARLES T. PORTER, PHILADELPHIA, PA.

The central Edison station of the first district in New York city will, when fully equipped, be supplied with twelve dynamos, each of which is nominally rated as a 1200-light machine, at 16 candle-power incandescence, but is capable of supplying 1400 lights of this power continuously, and with high economy, without heating the armature, or burning or injuring the commutator or brushes. This increased capacity is due to improvements in the lamp itself.

The armature of each dynamo is driven by a Porter-Allen engine, of $11\frac{3}{16}''$ diameter of cylinder by $16''$ stroke, directly

connected, and making 350 revolutions per minute, giving a piston travel of 933 feet per minute.

The steam is supplied by eight Babcock & Wilcox boilers of 2000 aggregate horse-power, and which will work under a pressure of about 120 pounds. These occupy the basement of the building. Over them, the first and second floors being removed, an iron superstructure is erected entirely separated from the walls of the building, and on this the combined dynamos and engines are placed.

One-half of this equipment is now nearly ready for service, and the remainder is expected to be completed during the coming season.

The armature of the dynamo is of the form commonly known as the Siemens armature, but in its construction and "connecting up" it differs radically from all others.

The foundation of the armature, or the iron core which is built upon the shaft, is made up of sheet-iron disks, separated from each other by sheets of tissue-paper, and bolted together. This has all the advantages of a solid iron core in strengthening the magnetic field, while it completely prevents the great loss of power by local currents, which would circulate in the iron if it were solid. In the place of insulated wires, the cylindrical face of the armature is made up of heavy copper bars, trapezoidal in section, each bar being insulated, and also separated from its neighbors and from the iron core underneath by an air-space.

The connection between the bars on opposite sides of the armature, to form the electrical circuit, is made by copper disks, of the same diameter as the core. At each end of the core are one-half as many of these copper disks as there are bars, each disk being insulated from its neighbors, and the whole being bolted together in such a manner as to form, with the disks of sheet-iron constituting the core, one solid mass. Each disk is formed with projecting lugs on its opposite sides to which the two bars are connected.

The connections between the opposite surfaces of an armature are of no benefit in generating an electric current, but are a necessary evil, introducing useless resistance into the circuit. By using for this connection copper disks in the manner described, a great weight of copper is disposed in a limited space; and so this useless resistance, and consequent loss of energy, is reduced to a minimum.

This method, moreover, reduces the work to a simple machine construction, in which all the parts are duplicates, and the operations can be much cheapened and facilitated by the use of special tools.

The spaces between the armature bars admit of a free circulation of air, thereby preventing the accumulation of heat, and increasing to an enormous degree the capacity of the machine. The armature is at intervals wound with piano wire over the bars to resist the centrifugal force developed by their revolution.

The commutator and brushes of an electrical machine are the parts subject to the greatest depreciation. In this machine all parts of the end of the armature are so constructed as to be easy of access, and they can be quickly and cheaply repaired, or removed and replaced by new parts, when necessary. Any accident would require but a short stoppage for repairs.

Provision is made for keeping a continuous and rapid circulation of air over the entire face of the armature.

This armature is 27.8″ in diameter by 61″ long. The commutator adds 18″ to this length, and is itself $12\frac{3}{4}$″ in diameter. The armature shaft is of steel, $7\frac{3}{4}$″ in diameter, having a total length of 10′ 3″. The journals are $6\frac{1}{2}$″ in diameter by 15″ long, and run in Babbitt-metal bearings, in pillow-blocks of the box form, giving the greatest stiffness with minimum of weight.

Provision is made for continuous water circulation underneath the boxes, and for continuous lubrication, with traps to prevent the creeping of the oil along the shaft and reaching the commutator, and drains to receive it as it runs through the bearings and convey it to a drip pan.

The magnet is made up of two immense cast-iron "pole pieces," between the semi-cylindrical faces of which the armature revolves, twelve cylindrical soft iron cores attached to these pole pieces, and made magnetic by an electrical current circulating in the wire around them, and four soft iron keepers connecting the back ends of these cores. Eight of the cores are attached to the upper pole piece, and four to the lower one.

The width of these poles is 49″, and their height $61\frac{1}{2}$″. The length of the twelve soft iron cores is 57″, the diameter of the four upper ones is 8″, and of the eight lower ones 9″.

The four soft iron keepers are each 11″ wide by 9″ in thickness, and the total length of the magnet is 94″.

The magnet is insulated by cast zinc bases 3″ in thickness. The weight of the dynamo is as follows:

Armature and shaft,	9,800	lbs.
Two pillow-blocks,	1,340	"
Magnet, complete,	33,000	"
Zinc bases,	680	"
Total,	44,820	"

The copper is distributed as follows:

In the armature bars,	590	lbs.
" " disks,	1350	"
In the magnet wire,	1500	"
Total,	3440	"

Mr. Edison was early impressed with the conviction that to give steady and reliable motion to these armatures it would be necessary to connect an engine to each one of them directly. This combination has been termed by him the Steam Dynamo.

In adapting the Porter-Allen engine to this service a special construction in some respects was found to be called for. These special features will be briefly described.

It seemed important to avoid a rigid connection between the engine and the armature shafts, which would require the entire series of bearings to be maintained absolutely in line. In place of this, therefore, a self-adjusting coupling (see Fig. 33) has been introduced, which will permit of considerable errors of alignment without any abnormal friction being produced in the bearings.

The point of difficulty was the backlash, the engine having no fly-wheel, except the heavy armature itself, which was to be driven through the coupling. Provision was made for taking this up by steel-keys of a somewhat peculiar form, between which the tongues of the coupling move freely, while they themselves are immovable. These keys are held between set-screws threaded in wrought-iron rings covering the flanges on the ends of the shaft. All the faces liable to move upon each other are oiled from a central reservoir. This coupling is a very compact affair, without a projection anywhere above its surface, and gives every promise of completely answering its purpose.

The engine is made with a forked bed and two shaft bearings and a double crank, and so is completely self-contained. It is shown in plan and elevation, Figs 29 and 30.

The shaft having no support beyond these bearings on either side, unusual stiffness was required in the crank-pin to prevent deflection under the great strains to which it is subjected.

A novel form of pin (see Fig. 31) was proposed by Mr. Richards, which is found to possess all the rigidity required. It is provided with flanges, which are let into each crank, and held each by four screws, as shown, while the shanks of the pin are also forced firmly into the cranks.

Special appliances enabled the work of putting the cranks together in this manner to be done with extreme and uniform accuracy.

The engine is so arranged as to have the valve gear on the side furthest from the dynamo. The engineer has not to go between the engine and the dynamo, when running, for any purpose.

The connecting-rod (Fig. 32) is of steel, and the crank-pin boxes are formed directly in the end of it.

This end is finished from a solid forging, and chambered out for Babbitt metal. The bolts are then fitted, after which it is parted and holes are drilled for holding the Babbitt securely.

In the connecting-rods for single crank engines of this type permanent length of rod is secured by forming the crank-pin end solid, and taking up the wear by a wedge closing up the inside box. In these double crank engines this construction is impracticable, but the same object is attained by forming the cross-head end in the manner shown, in which the strap is made permanent, and the inside box is closed up by a key bearing against a steel plate.

The weight of the reciprocating parts of this engine is as follows:

Piston, with rod,	83 lbs.
Cross-head,	42 "
Connecting rod,	109 "
Total,	234 "

The initial acceleration of this mass, or the force required, on the dead centres, to give it the motion necessary to relieve the crank from strain is as follows:

$$350^2 \times .66 \times .000341 = 27.57,$$

or 27.57 times the weight of the mass, which gives

$$234 \times 27.57 = 6451 \text{ lbs.}$$

The formula is $R^2\ l\ c$, when

R = the revolutions per minute ;
l = the length of the crank in decimals of a foot ; and
c = the coefficient of centrifugal force.

The connecting-rod is 48", or six cranks, in length. This affects the initial acceleration, making this to be on the dead centre farthest from the crank 7526 lbs., and on the dead centre nearest to the crank 5376 lbs., a difference of 40 per cent.

The area of the cylinder is 98.2 square inches.

The area of the piston-rod, 1¾ inches diameter, is 2.4 square inches, leaving area of cylinder at crank end 95.8 square inches.

The initial accelerating forces are therefore as follows, viz.: At the end of the cylinder farthest from the crank 77 lbs., and at the end of the cylinder nearest to the crank 56 lbs., on the square inch of piston area.

The counterweight was after some trials fixed at 135 lbs. This leaves 99 lbs. of the reciprocating parts running unbalanced. It is found that this is not sufficient to disturb the stability of the engine, while on the other hand the counterweight is not so great as to exert an objectionable strain in the vertical direction.

The total weight of the engine is 6,445 lbs.

The engine and dynamo are mounted on a cast-iron base plate, made for convenience in two parts, and bolted together.

The dimensions of this base plate are as follows : Length, 14 feet ; width, 8 feet 9 inches ; and its weight is 10,300 lbs. The entire weight is therefore as follows :

Base plate,	10,300 lbs.
Dynamo,	44,800 "
Engine,	6,450 "
Total,	61,550 "

The large engraving is a perspective view of the Dynamo and Engine combined. (Fig. 35.)

The last and most careful test of one of these dynamos gives the following results, as shown by the indicator diagrams, which are here reproduced full size ; scale, 80 lbs. to the inch.

The lamps used in all the trials were of the older construction, of which 8½ lamps, at 16 candle-power incandescence, require one horse-power of electrical energy.

Since these were placed for experimental uses, improvements in the lamps have increased their economy, so that one horse-

power is sufficient to maintain fully 10 of the present lamps at 16 candle-power incandescence.

Diagram No. 1 (Fig. 34) shows the friction of engine and dynamo at 350 revolutions per minute, requiring 13.63 H. P.

Diagram No. 2 shows the resistance with the magnet circuit on = 19.17 H. P.

Field 5.78 ohms, 103 volts.

The increased resistance due to the magnets was 5.54 H. P.

Of this, the calculated energy developed in the magnets was

$$\frac{103^2 \times 44.3}{5.78 \times 33,000} = \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 2.46 \text{ H. P.}$$

Leaving energy to be accounted for by local currents in iron core of armature, and in armature bars, 3.08 H. P.

Diagram No. 3 shows the work done in maintaining 300 lamps.

These, in the ratio of $8\frac{1}{2}$ to 10, were equal to 353 lamps of the present construction. The pressure was maintained also at 102 volts, representing 25 candle-power, in place of 98 volts, representing 16 candle-power incandescence, which requires the number of lamps to be increased in the ratio of 102^2 to 98^2, or to 382 lamps.

The pressure of the armature was 104 volts, showing a loss in the conductor of 2 volts, which would increase the number of lamps as 104 : 102.*

The total correction is therefore as follows:

$$300 \times \frac{10}{8.5} \times \frac{102^2}{98^2} \times \frac{104}{102} = 389 \text{ lamps.}$$

The power exerted was 60.6 H. P., which gives to the indicated horse-power

$$389 \div 60.6 = 6.42 \text{ lamps.}$$

The magnet circuit had now a resistance of 5.28 ohms with 104 volts pressure, representing

$$\frac{104^2 \times 44.3}{5.28 \times 33,000} = \quad . \quad . \quad . \quad . \quad . \quad 2.75 \text{ H. P.}$$

Substituting this in place of 2.46 H. P. in the first trial, we have 19.46 H. P., which, deducted from 60.6 H. P., leaves net 41.14 H. P.

This gives $389 \div 41.14 = 9.45$ lamps per H. P.

* The conductors were insufficient, occasioning a loss that increased with the increase in the number of lamps.

Diagram No. 4 shows the work done in maintaining 700 lamps.

The pressure at the lamps was maintained, as in the preceding trial, at 102 volts, which required at the armature a pressure of 105 volts.

The total correction in this case is therefore

$$700 \times \frac{10}{8.5} \times \frac{102^2}{98^2} \times \frac{105}{102} = 919 \text{ lamps.}$$

The power exerted was 115.83 H. P., giving to the indicated horse-power $919 \div 115.83 = 7.93$ lamps.

The resistance of the magnet circuit was now 4.78 ohms, with 105 volts pressure, representing

$$\frac{105^2 \times 44.3}{4.78 \times 33{,}000} = \quad . \quad . \quad . \quad . \quad . \quad 3.1 \text{ H. P.}$$

Substituting this in place of 2.46 H. P. in the first trial, we have 19.81, which, deducted from 115.83 H. P., leaves net 96.02 H. P.

This gives $919 \div 96.02 = 9.57$ lamps per H. P.

Diagram No. 5 shows the work done in maintaining 1050 lamps.

The pressure at the lamps was maintained in this trial at only 99 volts, but this required at the armature a pressure of 108 volts, showing a loss of 9 volts in conduction.

The total correction in this case is thus

$$1050 \times \frac{10}{8.5} \times \frac{99^2}{98^2} \times \frac{108}{99} = 1375 \text{ lamps.}$$

The power was 168.4 H.P.

Giving to the indicated horse-power

$$1375 \div 168.4 = 8.16 \text{ lamps.}$$

The resistance of the magnetic circuit was now 3.28 ohms, with 108 volts pressure, representing

$$\frac{108^2 \times 44.3}{3.28 \times 33{,}000} = \quad . \quad . \quad . \quad . \quad . \quad 4.77 \text{ H.P.}$$

Substituting this in place of 2.45 H. P. in the first trial, we have 21.48 H. P., which deducted from 168.4 H. P., leaves net 146.92 H.P.

This gives $1375 \div 146.92 = 9.36$ lamps per H.P.

It will be seen that the losses of efficiency due to undiscovered resistances are only

In the first case, $10 - 9.45 = .55$ H.P. per lamp,

In the second case, $10 - 9.57 = .43$ H.P. per lamp, and
In the third place, $10 - 9.36 = .64$ H.P. per lamp,
Averaging 5.4 per cent.

The friction in the journals of the armature, when driven in this manner, does not increase with the resistance, and, on account of the action of the reciprocating parts of the engine, that in its bearings is also nearly a constant quantity, whatever the load may be.

The above figures show this very clearly, the subtraction of the friction diagram in each case exhibiting substantially the same net power per lamp.

Discussion.

Mr. Le Van: I would like to ask why they use Babbitt metal? I know that when I was a lad we used Babbitt metal because we had not the means of boring things properly. But in the present state of art I cannot see why the journal boxes should be made of Babbitt. I have never used it in my practice, and I never had a hot journal. I admit we do not run up to three hundred and fifty revolutions, but we do go as high as two hundred and fifty.

Mr. Porter: So far as my practice is concerned we use Babbitt metal in this case, because we use it in all cases. We have found it to answer our purpose admirably well. There may be some time when we shall see our way to using something better. But we do not feel as if we could try more than one experiment at a time, and we know precisely what Babbitt metal will do for us. It answers our purpose perfectly. We never have a warm bearing, and the Babbitt metal does not wear away. I do not see how we could run a steel connecting-rod with any other metal so well.

Mr. Le Van: I wanted to find out whether he puts the Babbitt metal into that box prior to cutting it apart, or afterwards.

Mr Porter: Afterwards.

Mr. Le Van: Do you find any difficulty?

Mr. Porter: Not at all. A chamber is bored out. Of course we cannot drill the holes in the bottom of the chamber for securing the Babbitt until after the boxes are cut apart.

Mr. Le Van: I presume the indicator used is a Porter-Allen Indicator?

MR. PORTER: No, sir. The indicator is the Tabor Indicator.

MR. OBERLIN SMITH: I would like to ask why it is found necessary to sacrifice simplicity by making a pair of independent journals for the engine; why the pillow-block of the dynamo could not have been run out into the main frame of the engine, in which case you would have the crank directly upon the end of the dynamo shaft.

MR. PORTER: The construction that Mr. Smith presents as an alternative, would be a crank on the end of a dynamo shaft, without any additional bearing whatever; that would lengthen the dynamo shaft considerably. It would be necessary to extend the dynamo shaft quite a distance to accommodate what is considered to be required between the engine and the dynamo. It would need to be two feet longer probably than it is now, and the shaft has to be subordinate to the armature. It was thought on full consideration, desirable to have the two entirely independent. The engine shaft can be taken out without affecting the dynamo. The dynamo can be taken out without affecting the engine. The armature is a very complicated construction, and the shaft on which it is built it is thought ought not to carry anything else whatever. There are other reasons also. In such a construction the engine would be a single crank engine, and the valve gear would have to be between the engine-bed and dynamo, which would not do.

MR. OBERLIN SMITH: There may be electrical reasons for this construction. I only suggested the other as a matter of simplicity. The extra length of the dynamo shaft after all would not be as great as the aggregate length of the two pieces of engine shaft and the dynamo shaft now is. As a matter of construction, aside from electro-engineering, it would seem to be simpler.

The difficulty about the valve gear that Mr. Porter speaks of could be obviated by putting it *outside* the engine and driving it with what is known as an "eccentric crank." Any distance necessary to maintain between dynamo and engine, could be occupied by an extra-long main journal, which would be no disadvantage—rather otherwise. The armature could be lifted out, as it is now, having nothing foreign upon it but the crank, which is little larger than the present coupling. Disconnecting the boxes at crank-pin would be no worse than taking apart the coupling.

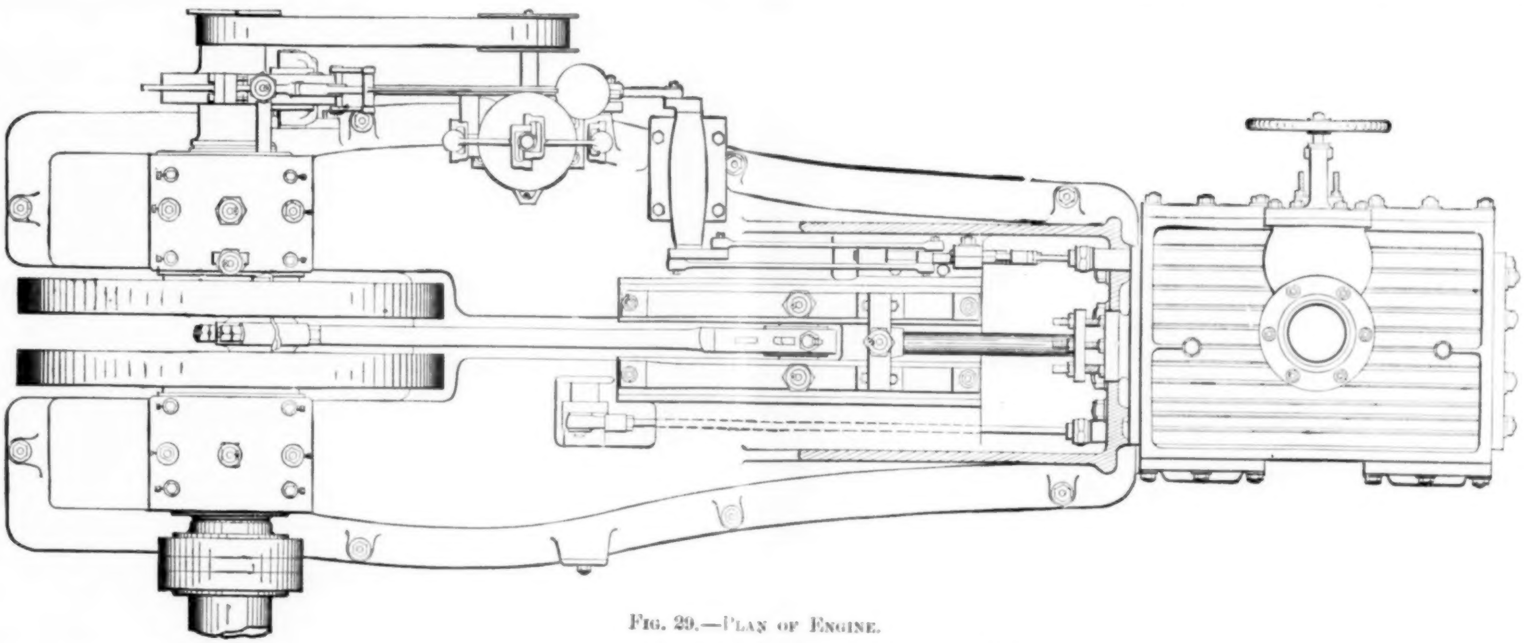


FIG. 29.—PLAN OF ENGINE.

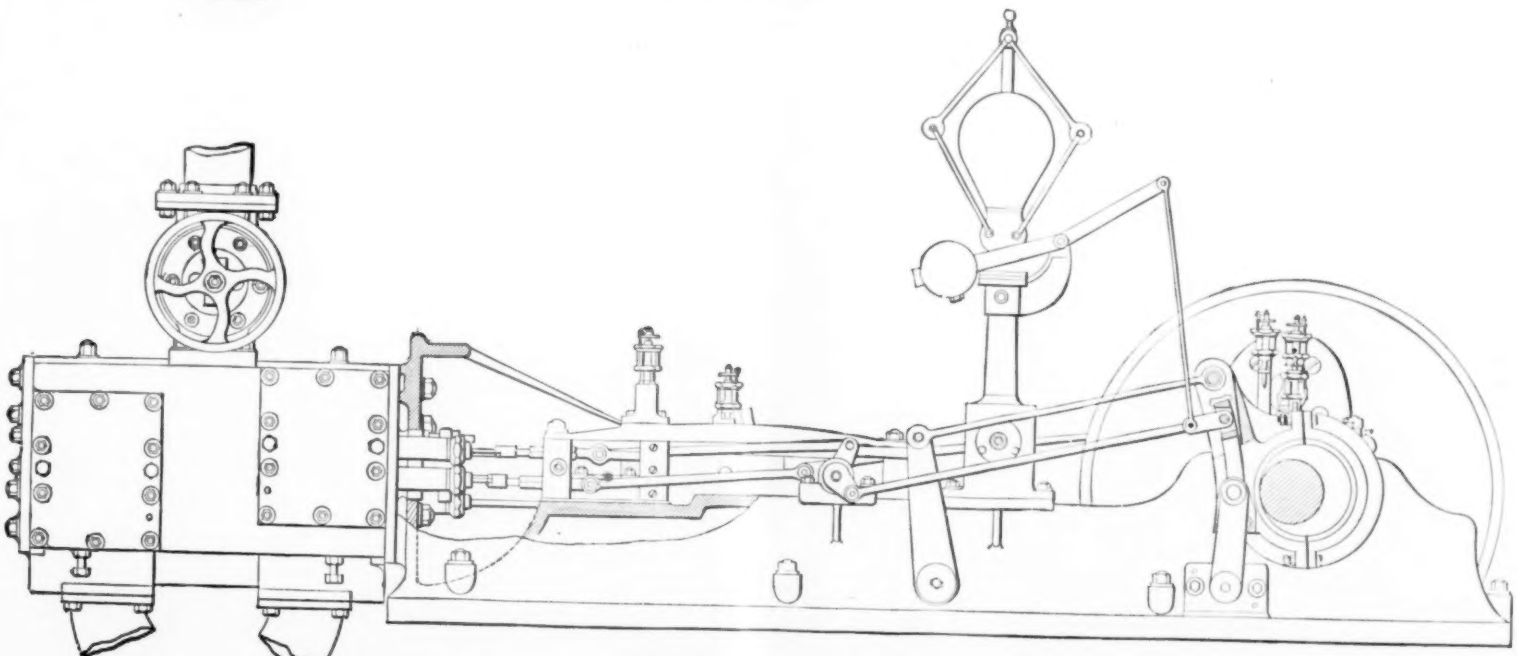
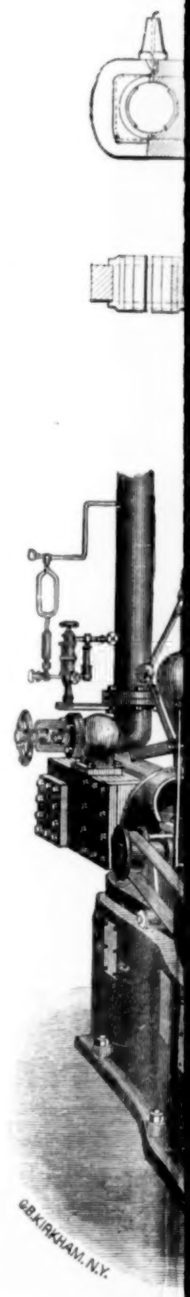
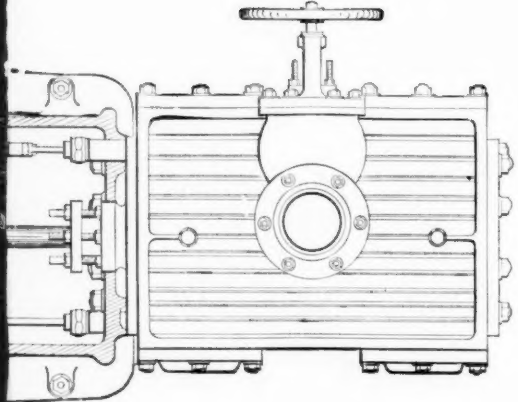


FIG. 30.—ELEVATION OF ENGINE.





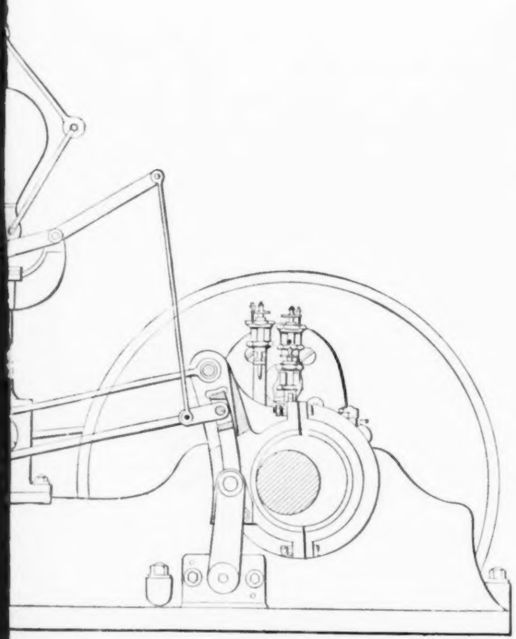
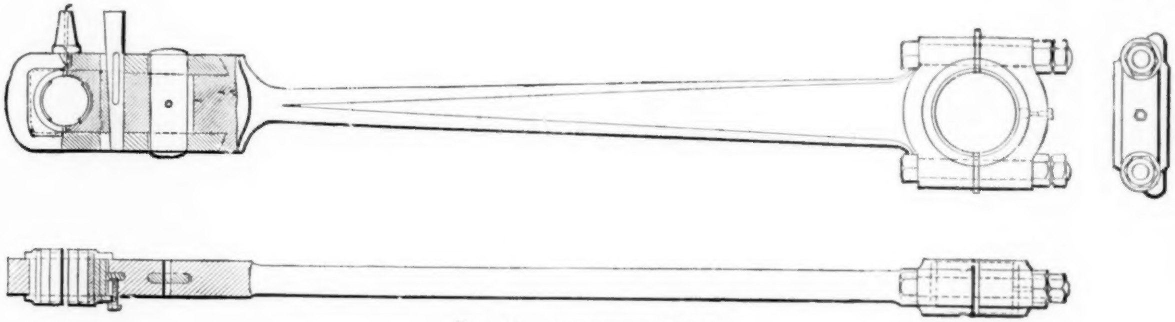
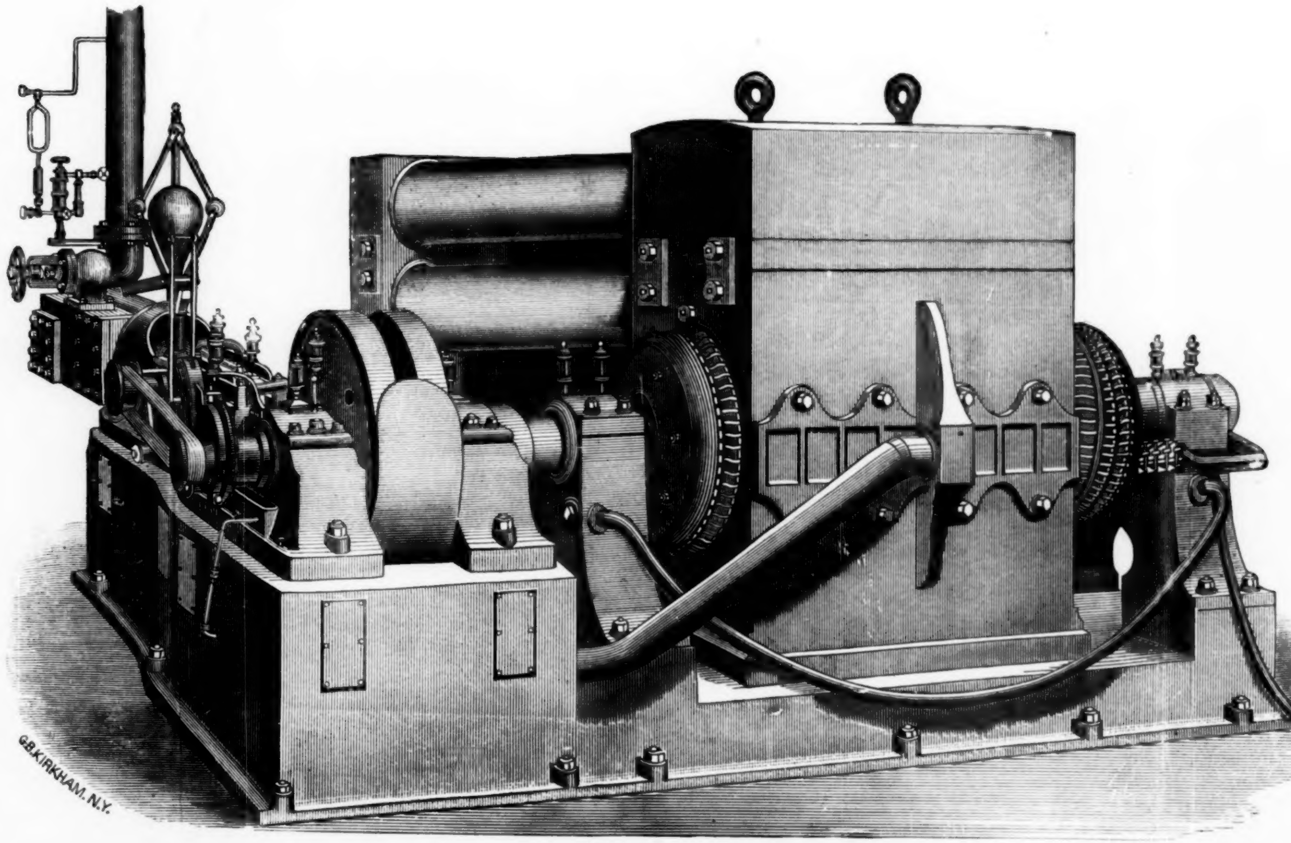


Fig. 32.—Connecting Rod.





Steam Dynamo (Dynamo and Engine Combined).

Fig. 35.

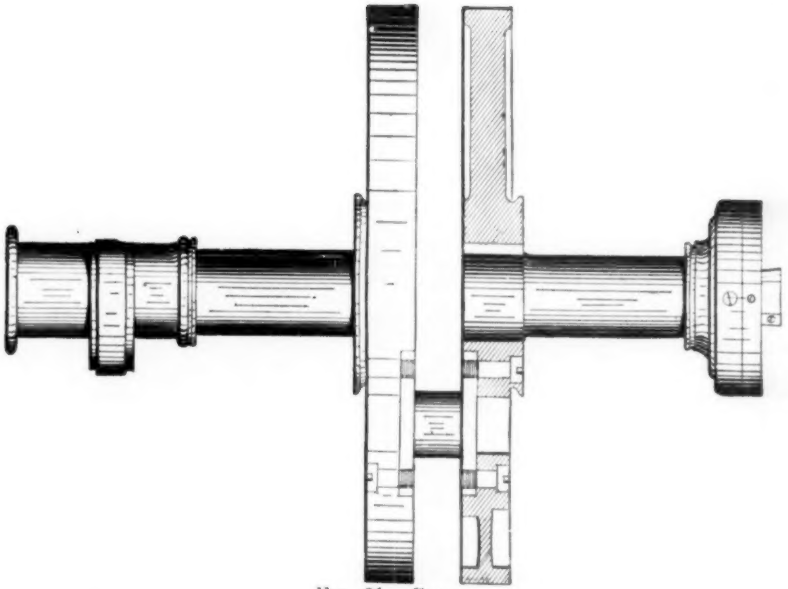


Fig. 31.—Crank.

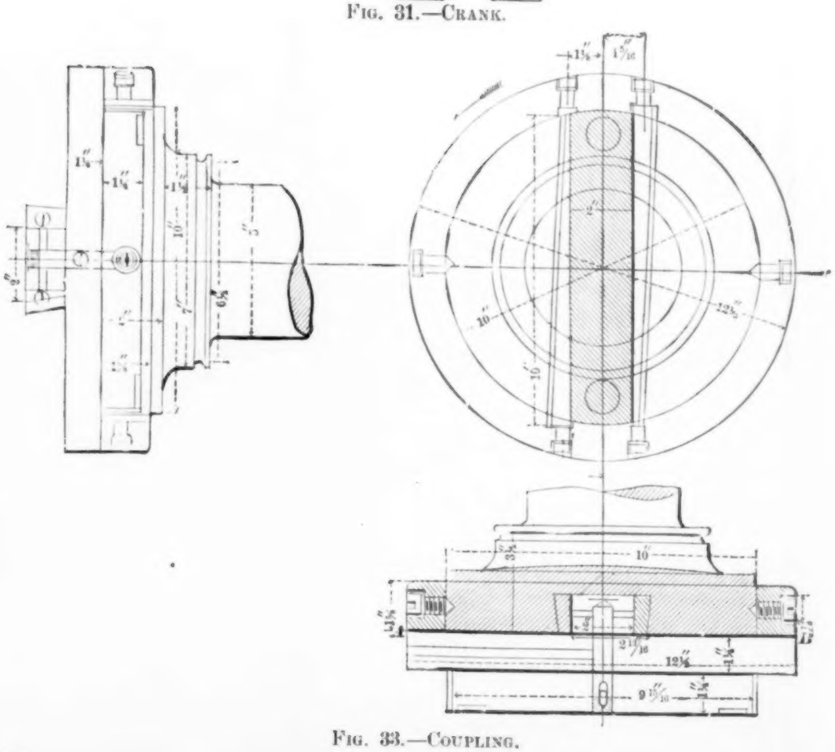


Fig. 33.—Coupling.

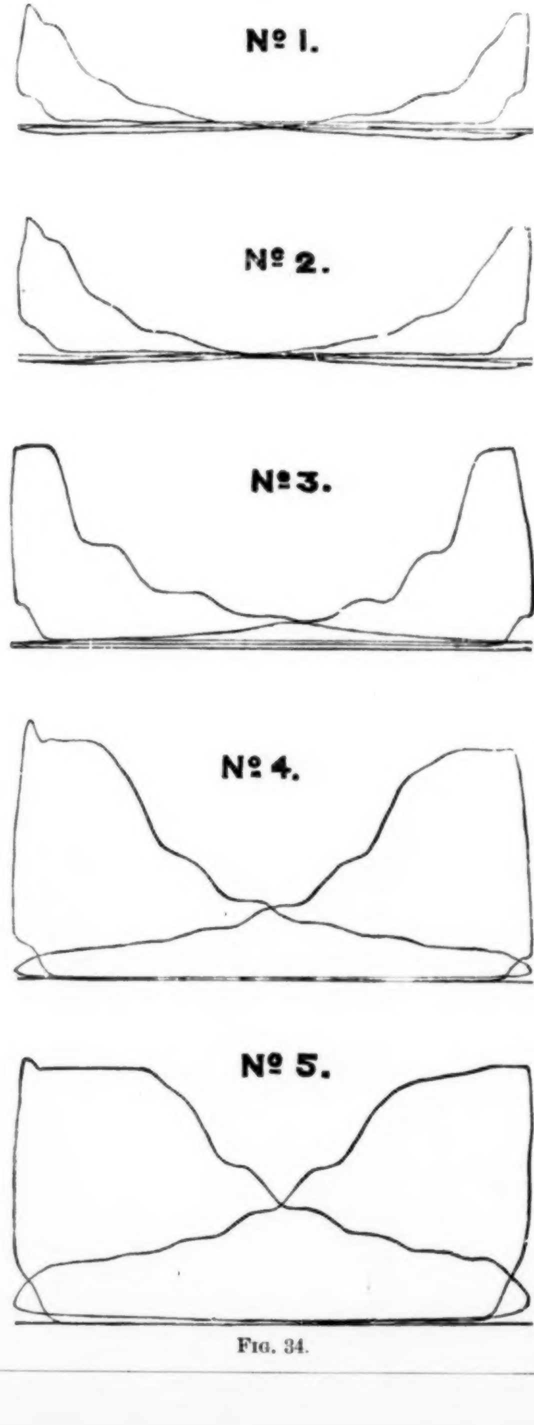


Fig. 34.

PROFESSOR THURSTON: I would like to ask Mr. Porter what pressure he can get on his Babbitt?

MR. PORTER: The pressure to the square inch?

PROFESSOR THURSTON: Yes.

MR. PORTER: I fancy it will stand anything.

PROFESSOR THURSTON: As much as bronze will?

MR. PORTER: It will flow, of course, where bronze will not, but I think we have had two thousand pounds on the square inch of Babbitt without having it flow at all. The Babbitt we use is made of copper, tin, and antimony, with twice as much antimony as copper.

MR. LE VAN: Babbitt's receipt is not as you mention. Probably you have a better mixture. I never found the Babbitt to stand as well as that.

MR. PORTER: I have forgotten our proportions exactly, but the amount of antimony is twice the amount of copper.

MR. LE VAN: I am satisfied that there are white metals that will carry strains better than Babbitt metal, and I think you have got one of those.

MR. BARR: There is a receipt in Haswell, and I would like to ask Mr. Porter whether the proportions he uses are the same as those given by Haswell, and if so we shall then know whether it is Babbitt's metal or something else.

MR. PORTER: I have forgotten the precise formula. I cannot answer the question. I have forgotten both the formula and the receipt given by Haswell. All that I remember is that we at one time employed equal proportions of copper and antimony, but wishing to make a harder metal we doubled the proportion of antimony. I don't carry figures very well in my mind. I ought to be familiar enough with that, but it has gone from me now. But the larger proportion of the alloy as everybody knows is tin.

LXXII.

NOTE ON THE ACTION OF A SAMPLE OF MINERAL WOOL, USED AS A NON-CONDUCTOR AROUND STEAM-PIPES.

BY

F. R. HUTTON, SCHOOL OF MINES, NEW YORK CITY.

THE samples exhibited to the society were taken from the outside of a five-inch steam-pipe, which carries steam at an average of 40 pounds pressure per square inch.

The pipe is one of three which lie close together, and are surrounded with a casing of galvanized iron. Inside this casing was packed the mineral wool which has acted on the pipe as shown. The casing was made in bandages, soldered together endwise, and at the joints. The only outlets were at the intervals where hanger rods hooked into rings on the pipes to support them. Where the pipes passed through the open air, it was possible for atmospheric moisture (fog, rain, or snow) to enter within the casing by trickling down the hanger rods. Where the piping was under cover, the moisture could only come from leakages at joints, or it might have been conveyed as steam along the tight casing. But so tightly was the wool packed in many places that long travel was prevented.

The samples were taken from a part of the pipe which it had become necessary to unsheath, where the run was under cover. Some are from the neighborhood of a flange-joint where a rubber gasket had deteriorated and permitted a slight leakage. Others are from a length of pipe which enters an elbow, where the expansion of a long run of pipe is concentrated. The flexing of this joint has caused the leakage, or else the moisture has come from a buried pipe which leaked underground some time before opportunity arose to repair it. In either case, the corrosion of the pipe seems to be the result of the action of mineral wool, when affected by moisture and heat. The intensity of corrosion may be inferred from the fact, that the threads of the pipe have been obliterated, partly by loss of top, no doubt, as well as by the filling in of the roots. These cakes may be lifted by the thumb-nail, where large. Smaller flakes are broken off by expansion and contraction.

The mineral wool, when sheathed in this way, seems to change its mechanical character when permeated by moisture. This change will be shown to be one result of a chemical decomposition. When dry it remains a non-adherent bulky and open mass all around the enveloped pipes. When it becomes wet—(it holds a great deal of water)—it becomes soggy, more compact, and falls away from the upper part of the sheathing, in some cases exposing the pipe. The saturation has been detected in one or two places by the deformation of the sheathing. Water may be squeezed out of the mass even after it appears dry.

To supplement the subject is exhibited a piece of $2\frac{1}{2}''$ pipe, which has been buried in mineral wool packed into a brick tunnel open at the ends. The top of the tunnel was flat, made of bluestone flags laid in cement, and covered all over with cement. Whatever moisture got into the tunnel should have evaporated outwards at the ends; but some did not, and has acted to corrode the pipe to great thinness on the lower side, and it was ultimately blown through at about the middle of its length. This pipe, as well as the five-inch pipe from which the scales were taken, were laid new and sheathed in the fall of 1879. They are, therefore, not quite two and a half years old. I have just dug up a $3''$ pipe laid in the summer of 1874 in earth which is not particularly dry. It is as good and strong as ever, and has had just the same work to do as the sample shown. Both were return pipes from steam-heating systems, carrying condensed steam back to the boilers.

It has, therefore, become necessary to look for the cause of this rapid corrosion. The mineral wool is made by disintegrating blast-furnace slag by a jet of steam or air. The wool must, therefore, contain whatever constituents were in the slag, and will be as diverse in different samples as the charges in different blast furnaces. But the general composition must be a compound of silica with bases, usually lime, magnesia, etc. It may be expected, therefore, that some characteristics of one sample of such silicates, when it becomes wet, may be taken as likely to hold for all. It is a known fact that these silicates, under *heat and moisture*, will decompose into the hydrated silicic acid, or gelatinous silica, according to the chemical formula below (taking lime as probable base) $CaSiO_3 + 2.H_2O = Si(HO)_4 + CaO$.

The CaO is caustic lime, which mere dampness will slack, and

cause to attack any iron surface; or, if that reaction does not satisfy, it may be suggested that the decomposition of the wool sets free oxygen in what the chemists call a nascent state, in which state it will assault the iron as likely as the lime. But the specimen which I took and exposed to a few simple qualitative tests gave a strong reaction for hydrosulphuric acid—the characteristic acid of corroded eggs. The element sulphur is not at all an unusual one in slags. It may be present as combined in a sulphide, or in a hyposulphite, probably with lime as a base. In either case, moisture and heat would release sulphur as an oxidizing agent, which would be only too likely to fasten on the iron. Qualitative tests have shown the unmistakable presence of sulphur in solutions of scale taken from the pipe, thus proving that corrosion must have been more active than that due to an innocuous non-conductor, even though wet.

Where the wool has remained entirely dry, the pipes are as good as new. The white stencil of the tube works is as legible as ever at such points. The inside of the sample shown is free as ever from oxide, but where moisture is to be expected, on the outsides of pipes—as it must be in expanding and contracting runs of long pipe—it would seem necessary for the engineer to be very certain of the absence from his non-conductor, of such an agent as has been determined in this particular case, and to have his silicate in a form which will not decompose. The action would seem to be no less decided than in the cases where unleached ashes have been similarly used. The experience is, therefore, put at the service of the society for the protection of its members against similar mishaps.

Discussion.

Mr. Kent: I think this an exceedingly valuable paper. It will not only prevent us from using mineral wool in its present conditions, but it will teach mineral wool men to purify their products from deleterious elements. I must disagree, however, with the gentleman in regard to part of the chemical theory, the first part and the second part. As to the third part I partially agree with him. I think it is exceedingly unlikely that there is any decomposition of silicic acid or of any other earth. It is also extremely unlikely that caustic lime can be formed. It is also unlikely that oxide of calcium, if formed, would oxidize the pipe. The trouble is that the mineral wool lets in, somehow or

other, sulphurous acid gas. If you have a freshly made sample of this mineral wool, you smell it. You have present then sulphurous acid gas and sulphide of calcium. You may have sulphide of sodium and sulphide of potassium. You have free sulphurous gas. You will not have sulphuretted hydrogen at all, except by some subsequent decomposition. Sulphuretted hydrogen could not exist at a fusing heat. The chemical reaction that takes place is the oxidation of sulphurous acid into sulphuric acid by the oxygen of the water and air, especially in the presence of oxide of iron, or even free iron. I have made a synthesis to prove that sulphurous gas added to water, and that to iron, will oxidize it with tremendous rapidity, forming sulphate of iron, which will dissolve in impure water the same as this gentleman has found; the water solution of this iron will show sulphuric acid. You will find that recorded in the *Journal of the Franklin Institute* for 1875, in connection with the destruction of bridges due to the presence of sulphurous acid in the smoke from the coal burned on locomotives.

PROFESSOR THURSTON: I would like to ask Professor Hutton if it is proved that caustic lime will produce corrosion?

PROFESSOR HUTTON: I perhaps ought not to say proved. The hypothesis has been advanced that external corrosion of boilers set in lime mortar is the result of the calcination of that lime. I have taken that hypothesis for all that it is worth, and simply reproduce it in that form. I have no exact knowledge, no direct experiments to report on this subject.

PROFESSOR THURSTON: I asked the question because I have been accustomed to keep caustic lime in my cases with my iron to protect it from corrosion, and my object was not to secure the absorption of moisture, but to secure the absorption of the carbonic acid that might be present. I did not suppose that moisture would do any harm.

MR. WOODBURY: Is not the rusting of iron by mortar somewhat dependent on heat? We have wire lathing that does not rust, and in the blowers of mills where the nails run through there is no rust, but plaster of Paris will, of course, rust iron very rapidly.

PROFESSOR THURSTON: I presume that the mortar is never in perfect contact with the iron where corrosion occurs. There is a crack which holds the moisture, and that may lead to decomposition. I think Professor Calvert's experiments will throw a

good deal of interesting light on the matter. He investigated the reaction between oxidizable metals and gases, and as I remember now he never found oxidation occur at all where carbonic acid was not present. My theory has been in using caustic lime to prevent corrosion, as I say, that it should take up the carbonic acid. As long as it is purely caustic it will take up the moisture; after it is slaked it will do that no longer.

PROFESSOR HUTTON: My impression is, though, Mr. President, that the point as to the decomposition of silicates under heat and moisture is a patent fact, although I cannot myself give references to the subject. I have been told so. When this matter was brought to my mind I at once went to Professor Egleston, our Professor of Metallurgy at the School of Mines, and from him that statement of the decomposition of silicates comes. My own theory was the sulphate theory; I know by experiment that that is correct. This other theory is also advanced, but not directly upon my own authority nor my own experiments on which the discussion rests.

PROFESSOR THURSTON: As to the fact of corrosion there is, however, no doubt.

PROFESSOR HUTTON: There is no doubt about that.

PROFESSOR THURSTON: This reminds me of an interesting fact in connection with this paper. One of our members, who had had a very large experience in marine work, has been trying to get a non-conducting material for the protection of his boilers. I talked with him one day about some boilers he put in some of the Sound boats. He said he had given up there the use of hair-felt. He found that where he used it, corrosion was accelerated on the *inside* of the boiler. So seriously did it occur, especially about the steam-chimneys, he gave it up. He attributed it to hair-felt, and he satisfied himself by taking off hair-felt and replacing it with asbestos and other material, and shifting the position until he made up his mind that hair-felt did that.

MR. BARR: Did he say what particular kind of corrosion?

PROFESSOR THURSTON: I do not remember that he did. It thinned his boilers very considerably under these sheets of hair-felting, but he said it was so serious that he had given up the use of it.

MR. BARR: I wonder if he ever saw a steamship boiler that was not corroded in that way, whether hair-felting was used or not?

THE PRESIDENT: He is a man who I do not think would be mistaken on the subject, as he has very great experience.

MR. PARTRIDGE: It has been repeatedly stated that ordinary glass under the influence of heat and moisture is decomposed. It is certain that certain kinds of glass are easily corroded by moisture, though the process is a somewhat slow one. Old bottle-glass buried in the soil for a comparatively short time will show signs of corrosion; not unlike that of the ancient Greek glass in the Cesnola collection in the Metropolitan Museum. Though this action has not been very closely studied, the resulting surfaces are precisely similar to those obtained by the use of hydrofluoric acid in producing iridescent glass.

Why should not a similar decomposition take place with an imperfectly formed glass like mineral wool, in which there is likely to be a large excess of some of its constituents, especially those sensitive to the action of heat and moisture?

PROFESSOR EGLESTON: The paper which Mr. Hutton has just read is one of much interest, as blast-furnace wool is being used on a very large scale as a non-conductor. This is not the place to discuss the characteristics of blast-furnace slag, but a knowledge of a few of them is necessary in order to fully understand how it is likely to be affected. Blast-furnace slag from which the wool is made is not a material of constant composition; it varies not only in different districts, but with the same furnace under varying conditions. It is the only means by which the sulphur remaining in the ore can be removed in any appreciable quantity, and in furnaces running upon sulphurous ores the slag is made of such a composition as will contain as much as possible of the sulphur contained in the ore. While the slags are variable so far as their ultimate chemical composition is concerned, there are a few characteristics in which they are all alike; one of these is that they gelatinize with acids. It has been supposed until within a few years that silicates were not usually attacked except by the mineral acids; it is, however, known now that not only are other silicates attacked, but that all these silicates, forming blast-furnace slags, are attacked with great ease by organic and other acids, such as would be likely to be found in the ground. The sulphur, as will be seen in the analyses below, is in the slag mostly as a sulphide, probably of calcium.

ANALYSIS OF BLAST-FURNACE WOOL REMOVED FROM PIPES AT COLUMBIA COLLEGE.

Water,	1.08
Potash,	0.19
Soda,	1.75
Magnesia,	19.82
Lime,	26.56
Sesquioxide of iron,	0.64
Alumina,	7.84
Sulphur,	2.46
Silica,	38.97
	99.31

SOLUBLE IN WATER.

Water,	1.08
Potash,	0.19
Soda,	1.75
Magnesia,	0.12
Lime,	1.61
Sulphur,	0.23

INSOLUBLE IN WATER.

Magnesia,	19.70
Lime,	24.95
Sesquixoide of iron,	0.64
Alumina,	7.84
Silica,	38.97
Sulphur,	2.23
	99.31

ANALYSIS OF SCALE FROM PIPE.

Protoxide of iron,	3.98
Sesquioxide of iron,	81.51
Sulphuric acid,	3.75
Water,	4.38
Lime,	3.09
Magnesia,	1.07
Silica,	2.46
	100.24

After the slag has been exposed for some time to moisture the sulphur is transformed into sulphuric acid, attacking the iron or whatever other material there may be for it to attack. Moisture simply leaching through the slag would absorb sulphuric acid enough to give a decided reaction and to attack the iron. I have given above the composition of the wool as used around

the pipes, the parts which are soluble, and those which are insoluble in water before any action on the pipes commenced.

I have also given the analysis of the scale which was removed from the pipe, which shows that the action of corrosion on the iron was that of sulphuric acid. The slag transformed into wool does not differ at all from the slag in its solid form, except in the fact that it is capable of retaining a very large amount of air. To this and this alone is its non-conductive property due. It is, moreover, in this state much more easily attacked by any decomposing agent than when solid.

If this slag becomes packed in any way it loses a considerable portion of its non-conducting power, and if it becomes moist it loses still more, and is very likely to pack and become worthless. Heat and moisture will decompose the slag. The slag may become decomposed with the separation of gelatinous silica, and when heated, even slightly, in this condition would certainly attack the iron, not only as ordinary water attacks iron, but because it contains sulphates leached out.

Now, if in addition to this the pipes are buried in such way that they receive the superficial drainage, that exerts another more powerful action, for not only will the slag be attacked by the moisture, but the organic acids will further attack the slag and decompose it, rendering it entirely unfit for the purposes for which it is used. So long as the wool is kept dry and is not allowed to pack, there probably is no other substance that is as good for the purpose. The moment, however, that it becomes moist it is certain that the material then becomes dangerous to the pipes it covers. Those of us who are metallurgists have known of these facts for a long time. I made allusion to some of them in the Hartford meeting, when Mr. Emery announced his extremely interesting experiments on the conductivity of heat through various substances.

One thing must be understood from the accident which Mr. Hutton describes, that wherever blast-furnace wool is to be employed absolute freedom from moisture must be insured.

There are thus several inconveniences in the use of this material:

1°. If it becomes packed it loses its conductive power.

2°. If it becomes moist it sags together, becomes packed, and is worthless.

3°. If the moisture is at all constant there will be a decom-

position of the slag, and an attack on the iron by the sulphuric acid set free, or the organic acids if the material comes from the drainage of the soil.

It becomes, therefore, a matter of very great importance to engineers using this material, that they should prevent any of these different things from occurring; and then the material is one of the most valuable non-conducting substances known.

LXXIII.

ON A THEOREM OF RANKINE RELATING TO THE ECONOMY OF SINGLE-ACTING EXPANSION ENGINES, FIRST PUBLISHED IN 1851.

BY

WILLIAM P. TROWBRIDGE, PROF. ENG., COLUMBIA COLLEGE, NEW YORK CITY.

THE object of the theorem above referred to was, in the words of the author, "to investigate and explain the method of determining the rate of expansion, and consequently the dimensions and proportions of a Cornish engine which, with a given maximum pressure of steam in the cylinder, at a given velocity, shall perform a given amount of work at the least possible pecuniary cost, taking into account the expense of fuel and the interest of capital required for the construction."

He further states, as a fundamental proposition, that by increasing the ratio of expansion in a Cornish engine the quantity of steam required to perform a given duty is diminished, and the cost of fuel and of the boilers is lowered. But, at the same time, as the cylinders and every part of the engine must be made larger to admit of greater expansion, the cost of the engine is increased.

"It thus becomes a problem of maxima and minima to determine what ratio of expansion ought to be adopted, under given circumstances, in order that the sum of the actual cost of fuel and interest of the capital employed in construction may be the least possible as compared with the work done."

It is somewhat remarkable that this theorem is nowhere alluded to in the author's subsequent elaborate treatise on the steam

engine; while on the other hand he was the first to formulate in that treatise, definitely, the true theory of the efficiency of the steam in the cylinder of an engine, and to explain how the combined efficiencies of the boiler, engine, and mechanism are to be ascertained from a purely mechanical and theoretical point of view. During the thirty years that have elapsed since the publication of the theorem, its value and importance, if either can be attached to it, have been ignored not only by all eminent writers on the steam engine, but by those most interested, the designers and users of steam engines.

It is reasonable to suppose, from these circumstances, either that there is an inherent fallacy in the theorem itself, or that engineers and business men have found it to be, even if true as a mathematical proposition, inapplicable in designing engines, or in using them.

An apology ought to be offered for asking the further time and attention of this society to a subject upon which there can be very little difference of opinion among well-informed engineers, as far as its theoretical aspects are concerned; but in the recent renewal of the discussion, upon the basis of this old theorem of Rankine, such positive grounds are taken in regard to the necessity of a radical change of views and of practice among engineers concerning the proper method of ascertaining the conditions of maximum economy in the application of steam-power, that a thorough criticism of the new methods seems to be called for. In order to do this, it is necessary to enunciate the theorem in its mathematical form.

Let p_e represent the mean effective pressure in the cylinder of an engine per square foot of piston, and V_2 the volume in cubic feet generated by the piston in one hour; then $p_e\ V_2$ will represent in foot-pounds the work per hour of the weight of steam admitted to the cylinder. Let W represent this weight and h^1 the cost of producing it, including the cost of fuel, and the hourly interest on the cost of the boilers $\frac{h^1}{W} = h$ will be the cost of producing one pound hourly.

Let K^1 represent the total interest on the cost of the engine, A the area of the piston, and K the interest per hour of the cost of the engine per square foot of the piston, then

$$K^1 = K.\,A.$$

The assumption made is, that the work in foot-pounds divided by the cost of the work must be a maximum for greatest economy; that is, if y be this ratio

$$y = \frac{p_e V_2}{h. W. + K. A.} \text{ must be a maximum.}$$

Let l represent the length of stroke, n the number of revolutions per hour, r the ratio of expansion, then

$$W = \frac{A.l.n}{r} . D$$

D being the weight of a cubic foot of steam at the initial pressure.

The above expression then becomes

$$y = \frac{p_e V_2}{h. \frac{A.l.n}{r}. D + K.A.}$$

$$= \frac{A.l.n \left[\frac{p_1}{\gamma - 1}\left(\frac{\gamma}{r} - \frac{1}{r\gamma}\right) - p_2\right]}{h. \frac{A.l.n}{r\, v_1} + K.A.}$$

r only being supposed variable in the second member, and in which p^1 is the initial pressure, γ, the exponent of v in the equation of the adiabatic curve of expansion, $pv\gamma = p_1 v_1 \gamma =$ constant, and p_2 the back pressure.

The result of the operation for finding the maximum of y by the calculus is an equation between the values of V_2, K, h, A, and r, as follows, supposing y to be $\frac{10}{9}$

$$h \frac{A.l.n}{v_1} \left(p_1 r^{-\frac{10}{9}} - p_2\right) = K.A \left[p_1 10 - 10 r^{-\frac{1}{9}}\right]$$

This result and the former expressions will be recognized as those given in a paper read at the Hartford meeting of the society by Messrs. Wolff and Denton, as being substantially the same as those of Rankine. In this expression v_1, represents the value of one pound of steam at the initial pressure p_1, and $\frac{1}{v_1} =$

D, D being the weight of a cubic foot of steam at the same pressure.

The usual mode of stating the efficiency of the steam in the cylinder of an engine is

$$E = \frac{p_e V_2}{H . \frac{A\,l\,n}{r} D . \times 772}$$

In this expression no element of cost enters, but the denominator represents the number of foot-pounds of work which enters, *as heat*, into the cylinder each hour.

H being the heat evaporation, $\frac{A.l.n}{r}$ D the weight W, and 772 the dynamic equivalent of a unit of heat. The maximum of this expression corresponds to such a degree of expansion by the adiabatic curve that the terminal pressure in the cylinder is just equal to the back pressure p_2. *The maximum of y* will correspond to a less degree of expansion, or to more steam used in proportion to the work developed.

The work p_2 V_2 for any degree of expansion may be represented by a rectangle of which the base is V_2 and the altitude p_e. The denominator may also be represented by a rectangle having the same base, but with a much greater altitude. The efficiency E is the ratio of these rectangles, or what is the same thing, the ratio of the altitudes of the rectangles. A somewhat similar process may be applied to the ratio giving the value of y, as explained by Rankine and worked out for varying values of the mean effective pressures and for various engines and boilers by Messrs. Wolff and Denton in the paper above referred to.

The graphical process thus introduced by Rankine shows at once the ratio of expansion which gives the maximum of y, or the rate of expansion which gives the greatest number of foot-pounds for the least amount of money, according to the author, *when his assumed premises are accepted.*

In regard to the maximum of E, the mechanical efficiency, a discussion by Rankine, found in his work on the steam engine, is a legitimate and correct one, but the theorem which introduces the cost is, at least when applied to modern steam engines, fallacious, inasmuch as the *premises assumed are not true.* It is a very ingenious discussion, considered as a mere mathematical problem, admitting all the assumptions; but if these assumptions are not correct it must be considered, as it is

practically, mere play of mathematics without practical value. In this presentation of the matter from a purely theoretical standpoint, the secondary influences of cylinder condensation, clearance, etc., are not considered.

The first false assumption is in the total cost of making steam per hour, $h. W.$ $h.$ is a constant, and is the cost of evaporating one pound of steam, including interest on cost of boiler; and when multiplied by the weight W it is assumed that the cost of a boiler constructed to evaporate this quantity of steam varies with the quantity of steam produced.

Whereas it is well known that the *same boiler* will produce more or less steam depending simply on the draft, and upon other circumstances not introduced. No exact relation of a general nature exists between the cost of a boiler and the quantity of steam it produces. Moreover, the chimney, or other appliance for producing draft, is an essential part of the boiler, and its cost should be included in the cost of making steam. The relation of cost to the quantity of steam produced is thus still more uncertain.

In the discussion of Rankine's theorem, by Messrs. Wolff and Denton, and by Prof. Thurston, who adopts and indorses their discussion, the quantity h is made to include also hourly wages of firemen, coal-passers, interest, a redemption annuity, or sinking fund, for the whole *supposed* lifetime of the boiler, etc. This accumulated quantity, h, multiplied by the weight of steam used at different grades of expansion, is taken at the hourly cost of making the quantity of steam W. It is hardly necessary to dwell on the fallacy of these assumptions, as the error must be apparent from the above statement, which will scarcely be denied by those conversant with steam apparatus.

The second false assumption is in making the total cost of an engine proportional to the area of the piston.

The value of K in the formula is the interest on the cost of the engine divided by the area of the piston. It is well known that the cost of modern steam engines does not vary as the piston area, nor as the volume of the cylinder.

The following statement, taken from the yet unpublished records of the Tenth Census, has been furnished me by Mr. Charles H. Fitch, special agent of the census, who has been engaged under my direction in determining the statistics of engines and boilers.

Cylinder Capacity and Cost.

"The following table exhibits comparatively the relations of cylinder capacity, weight, and cost in steam engines of the horizontal plain slide-valve type, rated at from eight to one hundred horse power:

Cylinder capacity of Engine.	Ratio of stroke to diameter.	Price per cubic foot of cylinder.	Weight of engine per cubic foot of cylinder (lbs.).
0.19	2.00	$1,910 00	8,684
0.27	1.71	1,392 00	6,296
0.46	2.00	1,113 00	7,500
0.59	1.77	952 00	7,118
0.72	1.60	872 00	6,944
0.90	2.00	749 00	6,264
1.31	1.66	707 00	6,183
1.58	2.00	644 00	5,860
1.79	1.43	633 00	5,168
2.14	1.71	569 00	5,023
2.79	1.50	497 00	4,337
3.48	1.87	451 00	4,253
3.53	1.33	509 00	5,241
4.41	1.66	448 00	4,736
4.35	1.20	517 00	4,638
5.44	1.50	459 00	4,964

"It is obvious that no formula can truly exhibit the relative changes of price and capacity, which does not consider the actual sizes of engines compared. The examples cited present an unusual degree of uniformity, a line of engines rated at uniform piston speed, and of similar excellent workmanship and finish.

"Between different styles and qualities of engines there can be no very definite comparison. For the same cylinder capacity a finely built, closely fitted engine may cost twice as much as an engine of inferior workmanship."

Rankine evidently assumed that the cost is proportional to the volume of the cylinder or to piston area, because this is the only assumption that will enable an engineer to *design an engine with a given power*, the steam being cut off at the point of the stroke determined by his theorem.

He gives an example by designing an engine of 100 H.P., having first found the proper ratio of expansion for a cylinder having a unit area of piston and a given speed. He finds the cost of a 100 H.P. engine of the same speed to be by his process £6018, an assumed cost of £250 per square foot of piston. Of course, if his 100 H.P. engine, with all its appliances, was found, when actually constructed, to cost more or less than £6018 the whole process becomes invalidated.

It would seem that nothing more need be said to exhibit the fallacy of the assumptions or premises on which the mathematical work of the whole discussion is based. But we may place these fallacies on broader grounds.

There cannot be, from the nature of finance and pure mechanics, any exact mathematical relation between abstract mechanical laws and financial operations.

The former are invariable and immutable, the latter dependent upon bargain and sale, the efficacy of human labor, or upon human necessities, and sometimes on human follies.

No more conspicuous illustration of these truths, it seems to me, could be given than this plausible, but false application of mathematics, and especially of the calculus, to a problem in which the cost of an apparatus and its mechanical performance are introduced as elements of a formula which is claimed to be general in its nature and practically correct in its applications.

Looking at Rankine's theorem from another point of view it is claimed that although it is not applicable *for designing engines*, yet after an engine and boiler have been completed, and the actual cost of the whole plant is known, it is then practicable to determine for that engine the point of cut-off which will give the most power for the money already and actually expended.

Assuming, for instance, the principle that the power divided by its cost should be a maximum, the same mathematical expression

$$y = \frac{p_e V_2}{h.\,W + K.A}$$

is merely restricted to an apparatus of which the cost is known.

Taking this view of the problem the absurdity of including in any manner in the variable term of the denominator ($h. W$) the interest on the cost of the boiler, firemen's wages, insurance, depreciation of value from use, repairs, etc., is evident at once; because none of these items varies with the quantity of the steam used.

Moreover, it is not necessary to estimate the interest on the cost of the engine K by the square foot of piston, but the formula, admitting for the sake of argument its validity, should be

$$y = \frac{p_e V_2}{h. W + K}$$

in which $h. W$ includes only those items of cost which vary with the quantity of steam used, and in which K includes all the constant hourly expenditures of the plant, including boiler and engine. We should thus have to include in h only the cost of making one pound of steam per hour estimated from the price of coal, while K would necessarily embrace the following items:

1. Hourly interest on cost of boiler.
2. " " " engine.
3. " " " chimney.
4. " " " boiler room and engine room.
5. Wages of engineer and fireman per hour.
6. Insurance per hour.
7. Taxes per hour.
8. A portion of the wages of general foreman and manager per hour.
9. Estimated repairs per hour.
10. Sinking fund for redemption of cost of boiler and engine, estimated to last (blank) years.

Everything, in fact, must be included which can reasonably be charged to the cost of the power, as distinguished from expenditures for utilization of power and other expenses connected with it.

In this mathematical formula, for which it has recently been claimed that it furnishes "*the only correct solution which has ever been presented*," and that it is of "*immediate practical use*," we find all of these quantities.

Let us see how they are to be determined numerically:

Interest—Who shall establish the rate?

Cost of engine and boiler—What shall it include?

Boiler and engine room and setting—How shall the cost be separated from that of the rest of the plant, in a manufacturing establishment, or in a steamship from other parts of the structure?

Wages of engineers and firemen—What shall be done if these wages should happen to change from time to time?

Insurance—When a whole establishment is insured what part shall be charged to power?

Salaries of general foreman and manager—What part shall be charged to power?

Repairs—What amount shall be *estimated?*

Sinking fund—How *estimated?*

Who can estimate the life of a boiler or an engine?

All or nearly all of the above quantities can be assumed only by mere guesswork; there is not a shadow of a guide or a rule for most of them, not even the results of experience, which so often aid in the solution of practical problems.

If the quantities in the formula are arrived at by mere guess, and without experience to guide the person who guesses, of what value are the results?

There is one other important consideration which should not be lost sight of in applying this method to a given plant, viz., that not until all these questions of cost have been successively guessed at and thus established, and not until after the boiler and engine have been erected, and ready for running, will the manufacturer or the steamship owner know what power he has at his disposal. The power developed at the "business man's" economical point of cut-off depends on these items of cost, and he must accept what his guesswork has given him.

Possibly the power thus available will not run his works or his ship, and he may find that in attempting this mode of economy he is a greater loser in the end for want of sufficient power or from having too much power. The moment dollars and cents enter into a problem it ceases to be a mechanical and becomes a financial one; and in such problems there must always be two sides to the account.

A horse-power as power has no standard or intrinsic value; its value depends entirely upon its serving fully and precisely the objects for which it is employed.

A definite amount of power, just sufficient for performing a given work, has a certain value, where one-half or indeed any less power might be of no value, and more power might involve loss.

Steam-power is like a manufactured article, and the question of preventing waste in the manufacture, by high grades of expansion and costly engines, is one in which all the conditions and circumstances of the use of the power must be considered. It cannot be narrowed down to a mere ratio between the cost of the engine and the cost of the fuel, as is claimed in the new method.

The attempt to apply this new method to marine engines in public vessels, where no questions of interest and of profit and loss can enter, is not the least of the absurdities that have marked the discussion of the subject.

The introduction of the sinking fund idea as a part of the cost involves another absurdity, because the operation of a sinking fund is to reduce the principal of the debt, and the value of the quantity K, in the formula assumed as constant, is not a constant under this assumption, but a variable quantity, practically a vanishing quantity. Thus the validity of the mathematical discussion is destroyed, even if there were no other elements of unsoundness in the process. It seems to me unfortunate that crude ideas on this subject should have been put forth as the results of exact scientific investigation, and a theorem, practically abandoned by its author, invoked to persuade business men that our most eminent and successful engineers of the present day have been practically ignorant of correct principles regarding the economical use of steam.

Nothing tends more to bring science into disrepute with those engaged in industrial pursuits than the hasty announcement in the name of science of conclusions or results, as truths, which are merely personal and unverified speculations or false deductions from assumed and unproved premises.

LXXIV.

ON THE SEVERAL EFFICIENCIES OF THE STEAM-ENGINE, AND ON THE CONDITIONS OF MAXIMUM ECONOMY.

BY

ROBERT H. THURSTON.

Section I. Methods and Principles.

1. *The Several Efficiencies of the Steam-engine.*

In the design of the steam-engine the mechanical engineer has frequent occasion to solve certain problems relating to its economical performance, and especially to determine what proportions of engine and boiler are best adapted to give maximum economy of fuel or of money under certain conditions precisely defined in advance. Such problems may usually be solved by the determination of the ratio of expansion producing maximum economy under the given conditions. The methods proposed by the writer for the solution of these problems form the subject of this paper.

Several problems of this character may be classed together, all of which relate to one or another of the "Several Efficiencies of the Steam-engine," as the writer has called them.

These "Efficiencies" are:

(1) *The Efficiency of Fluid.*—This is measured by the ratio of work done by the working substance to the mechanical equivalent of the heat expended on it. In the perfect engine this efficiency is measured by the quantity $\frac{\tau_1 - \tau_2}{\tau_1}$; the range of temperature worked through, divided by the maximum, initial, absolute temperature of the fluid entering the cylinder of the engine. In real engines great losses occur by incomplete expansion and by direct transfer of heat from induction to exhaust without production of work.

(2) *The Efficiency of the Machine.*—This is measured by the ratio of the quantity of work transmitted from the engine to the "machinery of transmission" to the work done upon the piston by the working fluid.

(3) In some cases the product of the efficiency of the fluid by

the efficiency of the machine is called the *Efficiency of the Engine* or of the System.

(4) *The Efficiency of the Furnace* is the ratio of quantity of heat transferred to the working substance to that developed by the fuel.

(5) The *Total Efficiency of the Apparatus, or of Plant*, as the writer would term it, is the product of these several partial efficiencies, and is the fraction of the total calorific power of fuel which is delivered to the machinery of transmission as mechanical energy.

(6) *The Efficiency of Capital*, or the Commercial Efficiency of Steam Machinery, is measured by the amount of capital employed, or of the total running expenses per unit of a given power required and obtained; *i. e.*, it determines how small a sum will provide a given amount of power and *what size of engine must be selected for the given work.*

Each of the above efficiencies is made a maximum by a set of conditions, the determination of which constitutes an important problem in the science of engineering. Each must be solved, and in a certain definite order, before the engineer can feel perfectly confident of full success in the application of steam power to any given case. The determination of the efficiency of fluid is included in the problem relating to efficiency of engine, and this and all other efficiencies are included in the last,—the Efficiency of Capital,—which cannot be exactly determined unless they are first ascertained.

(7) In addition to the above, another problem may present itself to the user of power, although seldom to the designer, or to any one proposing to purchase a steam-engine,—the determination of the maximum economy of a given plant; *i. e.*, how the most work may be obtained for a dollar from a given engine already constructed. This is entirely a different problem from (6); its solution leads to very different results, and does not usually, if ever, determine maximum commercial efficiency, as will be seen later. Here, then, the problem relates to what may be called the "*Maximum Commercial Efficiency of a Given Plant.*"

(8) It may, finally, be necessary to determine still another question: "*What is the Maximum Amount of Power that can be profitably obtained from a Given Plant?*" This is a more commonly familiar problem than the last, and of more direct and practical importance in most cases.

2. *Furnace and Boiler Efficiencies.*

The first case which naturally presents itself to the designing engineer, that relating to *Efficiency of Furnace or of Boiler*, has been frequently studied, and is well understood. To secure maximum efficiency, the engineer must provide for:

(1) Complete combination of fuel and oxygen without excess of air supply.

(2) Rapid and concentrated combustion.

(3) Rapid and general circulation of the heating-gases and of the heated fluid.

(4) Ample area of well-arranged heating surface to transfer heat from the furnace gas to the water.

In the case of a steam-boiler, efficiency is a function of area of heating surface and of quantity of fuel burned on the given area of grate surface. Rankine deduces the expression

$$\frac{E}{E'} = \frac{B}{1 + \frac{AF}{S}}$$

in which $\frac{E}{E'}$ is the ratio of water evaporated per pound of fuel to that which would be evaporated were the whole calorific power of the fuel utilized. Then

$$E = \frac{BE'}{1 + \frac{AF}{S}}; \quad S = \frac{FA}{\frac{BE'}{E} - 1}$$

S is the area of heating surface per unit of area of grate, and F the number of pounds of fuel burned per hour per square foot of grate. The constant B is, for bituminous coal, burned in good boilers, about 1; A varies from 0.3 with forced draught to 0.5 with chimney draught, probably varying nearly as the square of the weight of air supplied the fuels. Where a forced circulation has been obtained, the writer has found a lower value even than 0.3. In experiments with anthracite coal he has usually obtained a lower value of B than is given above, varying from 0.85 to 0.90.

The engineer, in using the above formula, usually decides what efficiency he can afford to pay for, and then obtains the value of S and thus determines the size and weight of his boiler; he rarely makes $\frac{E}{E'}$ exceed 0.75, and will often find it best to

accept a much lower value in order to obtain maximum commercial efficiency. This case should be treated similarly to that relating to the commercial efficiency of engines described hereafter at some length.

It will be found that the maximum commercial efficiency of boiler—*i. e.*, the proportion of heating surface to grate surface or to fuel burned on the grate per hour, which gives the required amount of steam at least total expenditure—is determined by the equations,

$$S = A'F\sqrt{R}; \quad \frac{S}{F} = A'\sqrt{R};$$

in which S is the area of heating surface per unit of area of grate; F is the weight of fuel burned on that unit of area; A' is a coefficient varying from 0.5 with boilers of quick or forced draught and good circulation to 0.7 with boilers having sluggish draught and a less perfect circulation; R is the quotient obtained by dividing the sum of all annual expenses, dependent on amount of fuel burned, reckoned per pound of fuel and per square foot of grate, by the sum of all the annual expenses per square foot of heating surface per unit of grate area, so far as they are dependent upon size and character of boiler; as interest, repairs, and depreciation. *E. G.*—For a usual case in marine practice, $A' = 0.5$; $F = 12$; $R = 26$; $S = 30$. For a case of continuous operation of boiler, as in a flour mill, $A' = 0.6$; $F = 10$; $R = 25$; $S = 30$. For certain cases of occasional use, as in a steam yacht, $A' = 0.7$; $F = 12$; $R = 10$; $S = 28$; $A' = 0.6$; $F = 10$; $R = 8$; $S = 17$.

R sometimes becomes as great as 50 in ordinary practice, when fuel is expensive.

The proportions of boilers of any given class are seen to be dependent solely upon the quantity of fuel burned, and the relation existing between the two classes of expenses—those of operation and those of maintenance.

When the boiler is once constructed and set, it is sometimes found possible to use profitably a larger quantity of steam than it was designed to furnish, and it may become a matter of interest, if not of importance, to determine what amount of steam will give the largest quantity per dollar of total running expense. In such a case, the boiler is worked with a more rapid draught, and more fuel is burned on the grate, other conditions affecting

efficiency being constant except as dependent upon the quantity, F, which now becomes the independent variable. The total cost of steam now becomes the sum of all expenses, constant and variable ; and, calling K the annual cost of all items invariable with variation of quantity of coal burned, and $k = \frac{K}{G}$, this cost divided by area of the grate, it will be found that the "Maximum Commercial Efficiency of Plant," as the writer calls it, will be obtained when

$$F = \sqrt{\frac{kS + DS^2}{AC}};$$

when D is the annual cost per unit of S, as before, of items variable with S; and C is the annual cost per unit of F, of items variable with F. The boiler may often be profitably forced still further, until the cost of working no longer allows a profit on the steam made and used ; but this limit may be reached either at or beyond the value of F, just deduced ; it is found when, if k, C and D measure the cost of constant items of expense per unit of grate area of variable expenses for fuel and for boiler, and M is the *value* of steam, per unit of weight,

$$kG + CFG + DGS = MFGE$$

i. e., when the sum of all expenses becomes equal to the total *value* of the steam made. The analysis covering these cases will be given in a later paper.

3. *Efficiency of Engine.*

The Efficiency of Engine has been often studied by authorities accepted as standard, but almost invariably as a problem in thermo-dynamics, simply ; and the losses of heat occurring in consequence of the working of steam in a cylinder composed of a good conductor of heat have been left unnoted although frequently the most important of all the expenditures of heat taking place in the engine. Mr. D. K. Clark discovered this phenomenon in 1851, and described it clearly in his papers and later publications. Professor Rankine noted this method of waste, and describes the phenomenon fully as early as 1859,* but neither he nor any other writer, Clark and Hirn excepted, for many years, seems to have realized the extent and importance

* Steam-engine, etc., § 286 ; par. 2.

of this loss in all engines.* Prof. Cotterill alone, of all authors known to the writer, has treated this part of the problem of steam-engine efficiency in a manner that is at all practically satisfactory to the engineer.†

The writer has endeavored in an earlier paper‡ to show what conditions determine maximum efficiency of fluid and of engine. In a non-conducting cylinder, the maximum Efficiency of Fluid would be secured if the ratio of expansion were made nearly equal to the quotient of initial by back pressure; $r^n = \frac{p_1}{p_3} = \frac{p_1}{p_2}$, while the efficiency of engine would be made a maximum when the ratio is made nearly equal to the quotient of initial pressure by the sum of all useless resistance; $r^n = \frac{p_1}{p_b} = \frac{p_1}{p_2}$. When, however, as is always the case in practice, the steam is worked in a metallic cylinder, the best ratio of expansion is made very much smaller, and the efficiency of the engine is greatly reduced by cylinder condensation and re-evaporation, which produce a serious waste of heat. The extent of this modification has been indicated by the writer, and an attempt has been made to determine by a simple method based on experiment and observation what are the usually best ratios of expansion, and what the least probable quantities of steam and of fuel demanded per hour and per horse-power, at maximum efficiency by the principal standard types of engine.

In a still later paper§ the writer has exhibited at great length the differences in the behavior of steam expanding in a non-conducting vessel, and in the metal cylinder of the steam-engine, and has shown how to determine and construct true "Curves of Efficiency" for actual engines, exhibiting the character of this newly discovered curve, and its functions. It was shown that the total loss of efficiency of work, or of pressure, due to cylinder condensation, may be allowed for by taking for its value the expression $a\ r^m$, in which a is constant dependent upon the state

* Proc. Inst. Mech. Engrs., 1852; Railway Machinery, 1855; Handbook for Mech. Engrs., 1877.

† The Steam Engine considered as a Heat Engine; J. H. Cotterill, London and New York, 1878.

‡ On the Ratio of Expansion at Maximum Efficiency. Trans. Am. Soc. Mech. Engrs., 1881; Journal Franklin Institute, May, 1881.

§ On the Behavior of Steam in the Steam Engine, etc. Jour. Frank. Inst. Feb., 1881.

of the steam before expansion, r is the ratio of expansion, and $_m$ is an exponent dependent upon the method of variation of the proportions of the mixture of steam and water as expansion progresses.

The useful work per stroke is a maximum, and the ratio of expansion at maximum efficiency of engine is found, when the latter is of such value as to satisfy the equation:

$$r^{-n} - a\, r^{m-n} = \frac{p_b}{p_1}, \text{ nearly,}$$

and when, if c is the "cut-off"

$$c^{n} - a\, c^{n-m} = \frac{p_b}{p_1}, \text{ nearly.}$$

The value of the constant a varies from 0.1 to 0.2, in good engines, according to quality of steam supplied, and $_m$ may be taken at 0 in the best cases of well-designed compound engines, and as rising to 0.5 in unjacketed single cylinder engines; n is the exponent in the equation of the expansion line.

Studying these modified conditions as observed in practice, the best rates of expansion for maximum duty r_c^1, for several well-known and typical classes of engines are taken by the writer thus:

Probable Terminal Pressures and Rates of Expansion at Maximum Efficiency.

Case.	Initial Pressures. *Absolute.*		Speed of Piston.		SINGLE CYLINDERS. Class I.—Non-condensing.						Class II.—Condensing.						COMPOUND CONDENSING. Class III.								
					Unjacketed.			Jacketed.			Unjacketed.			Jacketed.			Sides jacketed.			Heads and sides jacketed.			Heads and sides jacketed with efficient superheating.		
					$p_t=p_v$		r_e^1	$p_t=p_v$		r_o^1	$p_t=p_v=p_c$		r_o^1	$p_t=p_v=p_c$		r_e^1	$p_t=p_v=p_c$		r_e^1	$p^t=p_v=p_c$		r_e^1	$p_t=p_v=p_b+p_f$		r_e^1
	P_1	P_m	V	V_m	Lbs. on sq. in.	Kilos on sq. cm.		Lbs. on sq. in.	Kilos on sq. cm.		Lbs. on sq. in.	Kilos on sq. cm.		Lbs. on sq. in.	Kilos on sq. cm.		Lbs. on sq. in.	Kilos on sq. cm.		Lbs. on sq. in.	Kilos on sq. cm.		Lbs. on sq. in.	Kilos on sq. cm.	
I.	40	2.8	400	122	20	1.4	2.0	20	1.4	2.0	16	1.1	2.5	13	.9	3.0	.9	.6	4.5	7½	.5	5	7½	.5	5
			625	185	20	1.4	2.0	20	1.4	2.0	13	.9	3.0	13	.9	3.0	.9	.6	4.5	7½	.5	5	7½	.5	5
II.	60	4.2	400	122	20	1.4	3.0	20	1.4	3.0	20	1.4	3.0	15	1.1	4.0	1.1	.8	5.5	8	.6	7.5	7½	.5	8
			625	185	20	1.4	3.0	20	1.4	3.0	15	1.1	4.0	15	1.1	4.0	1.1	.8	5.5	8	.6	7.5	7½	.5	8
III.	80	5.6	400	122	23	1.6	3.5	20	1.4	4.0	23	1.6	3.5	18	1.3	4.5	1.3	.9	6.5	3	.6	9	7½	.5	11
			625	185	20	1.4	4.0	20	1.4	4.0	18	1.3	4.5	18	1.3	4.5	1.3	.9	6.5	9	.6	9	7½	.5	11
IV.	100	7.0	400	122	25	1.8	4.0	20	1.4	5.0	25	1.8	5.	20	1.4	5.0	1.4	1.1	7.0	10	.7	10	7½	.5	13
			625	185	20	1.4	5.0	20	1.4	5.0	20	1.4	5.	20	1.4	5.0	1.4	1.1	7.0	10	.7	10	7½	.5	13
V.	120	8.4	400	122	27	1.9	4.5	22	1.5	5.5	27	1.9	4.5	22	1.5	5.5	1.6	1.1	7.5	11	.8	10.5	7½	.5	17
			625	185	22	1.5	5.5	22	1.5	5.5	22	1.5	5.5	22	1.8	5.5	1.6	1.1	7.5	11	.8	10.5	7½	.5	17
VI.	150	10.5	400	122	80	2.1	5.0	25	1.8	6.	30	2.1	5.0	25	1.3	6.0	1.8	1.3	8.5	12.5	.9	12	7½	.5	20
			625	185	25	1.8	6.0	25	1.8	6.	25	1.8	6.0	25	1.1	6.0	1.8	1.3	8.5	12.5	.9	12	7½	.5	20
VII.	200	14.1	400	122	36	2.6	5.5	29	2.1	7.	36	2.5	5.5	29	2.1	7.0	2.0	1.4	10.0	14	1.0	14	7½	.5	27
			625	185	29	2.1	7.0	20	2.1	7.	29	2.1	7.0	29	2.1	7.0	2.0	1.4	10.0	14	1.0	14	7½	.5	27

The terminal pressure $p_t = p^v$ is taken as equal to $p_3 + p^f$, the sum of back pressure and frictional resistance in non-condensing engines with low steam, and in highly superheated steam-engines.

Deduct 14.7 lbs. per sq. in. = 1 kg. per sq. cm. to obtain gauge pressures. Hyperbolic expansion is here assumed.

P_1 p^m are pressures in British and metric measures; V V_m are velocities in the same measures.

The probable minimum expenditure of steam per hour and per horse-power were also given as follows in the first of this series of papers:

Probable Minimum Weights of Steam per Hour per Horse-power.

r	W Pounds.	W_m Kilos.	r_0	W Pounds.	W_m Kilos.	r_0	W Pounds.	W_m Kilos.
3	32	15	8	20	9	13	17	8
4	27	12	9	19	9	14	16	7
5	25	11	10	19	9	16	16	7
6	22	11	11	18	9	20	15	7
7	20	9	12	17	8	25	15	7

Taking the probable minimum expenditure of coal per hour and per horse-power at *one-ninth* the weight of steam demanded, we get at the ratio of expansion giving a minimum cost of steam, the following:

Probable Minimum Weights of Coal per Horse-power per Hour.

r_0	W Pounds.	W_m Kilos.	r_0	W Pounds.	W_m Kilos.	r_0	W Pounds.	W_m Kilos.
3	3.5	1.6	8	2.2	1.0	13	1.9	0.9
4	3.0	1.4	9	2.1	1.0	14	1.8	0.8
5	2.8	1.3	10	2.1	1.0	16	1.8	0.8
6	2.3	1.1	11	2.0	0.9	20	1.7	0.8
7	2.2	1.1	12	1.9	0.9	25	1.7	0.8

For cases in which the boiler gives an evaporation of ten pounds of water per pound of coal we may get ten per cent. better figures.

The Efficiency of the Apparatus is the product of efficiency of furnace and boiler, the efficiency of engine, and the efficiency of mechanism of transmission. It is made a maximum when each of its factors is a maximum.

4. *Efficiency of Capital.*

The Efficiency of Capital, Case 6, is the most interesting of this series of problems of maximum efficiency, and its solution, by a practically correct method, giving reliable results accordant with experience, has been, by some engineers, regarded as one of the most important of problems now demanding the attention of the engineer. It is this problem which is proposed as the principal subject of the present paper.* In studying the efficiency of capital, it is first necessary to consider the elements of cost of power. The problem may be stated thus: *Given* the quantity of power required, to determine what ratio of expansion and what size of engine will give that power at minimum cost.

To solve this problem the engineer must know the cost of the engines, boilers, and appurtenances, and all items of running expense. Then making the sum of both items of variable annual expense—those variable with size of engine, and those variable with quantity of steam demanded—a minimum, the sum of these items and of all invariable expenses, *i. e.*, of the total running expense, becomes a minimum, and the problem is solved. A knowledge of these conditions and of all other expenses, constant as well as variable, is also essential to the treatment of Case 7, which may be thus stated: †

Given the size, power, and all items of cost, and running expenses of a known plant of steam machinery, to determine what method of working the steam, *i. e.*, what ratio of expansion, will give most work for a dollar of total expense of operation.

Since the economy of fuel and steam demands the use of a large engine, working steam with a considerable expansion, and gives reduced size and weight of boiler, it is evident that the first of these two problems is to be solved by determining what proportion of engine and boiler will be cheapest when summed up at the end of the life of the plant; this is settled when the ratio of expansion at maximum commercial efficiency is known, since the best size of engine and boiler is then fixed. The work may be done either by a large engine and a small boiler, or by a smaller engine supplied with more steam by larger boilers.

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* This problem was first enunciated by Rankine, and solved for the case of the non-conducting cylinder.—*Vide* "Phil. Mag.," 1854; "Miscell. Papers," p. 295.

† First treated, so far as the writer is aware, by Messrs. Wolff and Denton, who solved it for the ideal case.—"Trans. Am. Society Mech. Engrs.," 1880; "American Engineer," 1881.

The second problem, Case 7, is solved by determining what degree of expansion will give most power from an engine and boiler already installed, at least cost per horse-power. The first problem contains, as elements, all items of cost variable with change of proportions of engines and boilers capable of doing the same given quantity of work. The second problem considers every item of expense, and the amount of power is a variable quantity. Both problems require the study of the costs of steam power and the determination of the way in which each is related to total expense, and the manner in which each varies with variation of the variable quantities in either case.

If, therefore, we have given a certain annual invariable expense of operation, certain additional expenses variable with size of engine, and therefore with the ratio of expansion, r, adopted, and certain other additional expenses variable with quantity of steam demanded and with size of boiler needed, and thus also dependent upon the ratio of expansion at which that steam is used, we may call the two latter quantities, respectively, $f^{\text{I}}(r)$ and $f^{\text{II}}(r)$, while the constant part may be called C. Then the total annual expense is $f^{\text{I}}(r) + f^{\text{II}}(r) + C$, which is a minimum when the variable part, $f^{\text{I}}(r) + f^{\text{II}}(r) = f(r)$ is a minimum, and this is a minimum when its ratio to work done, $F(r)$, is a minimum, *i. e.*, when $\frac{f(r)}{F(r)}$ is a minimum, or $d\,\frac{f(r)}{F(r)} \div dr = O$. The value of r which satisfies this condition gives Maximum Commercial Efficiency.

The determination of the value of r which makes $\frac{f(r) + C}{F(r)}$ a minimum, gives the solution of Case 7.

Case 8 is solved by determining at what ratio of expansion the cost of power becomes equal to the market value of the power, less a paying profit.

The Annual Cost of Steam Power consists:

(1) Of certain expenses, which, in any given case, are usually invariable, whether the work is done by a large engine with high ratio of expansion and small boilers, or with a smaller engine working at a low rate of expansion and with larger boilers. These are usually: rent of building or interest on cost, taxes, repairs, etc., etc., of structure and location, the engineer's salary, and sometimes all or part of the fireman's or stoker's, also sundry minor expenses or a part of each of other expenses

which, as a whole, are variable. Both of the latter classes may usually be neglected in solving the problem here first considered.

(2) The interest on first cost of engine in place, the cost of repairs, and a sum which measures the depreciation in value of the machine due to its natural wear, or to its decreasing value in presence of changes that finally compel the substitution for it of an improved engine. Oil, waste, and other engineer's stores fall under this head. These items are variable with size and style of engine.

(3) The expenses of supplying the engine with steam. These are:

(*a*) The cost on fuel account of the steam supplied, and which includes, also, the cost of steam condensed *en route* to the engines and wasted by cylinder condensation and leakage, as well as that actually utilized. This total quantity of steam greatly exceeds that actually used in the production of power by simple transformation of heat energy. This item varies with the efficiency of engine and size of boiler demanded.

(*b*) The account of interest on cost of boilers in place and of their appurtenances, rent of boiler-room, depreciation, repairs, and insurance, which latter account is wholly chargeable to boilers. This is also variable with size of boilers.

(*c*) Cost of attendance in excess of the costs included in the constant quantity in item (1) and variable with size of boiler or quantity of steam demanded.

The salary of the engineer is usually not chargeable to either engine or boiler; his position is one of supervision over the whole apparatus, and a good engineer generally keeps the closest watch over the boilers. The engine can usually be trusted, much of the time, to take care of itself. With small engines, the engineer is also the fireman. With large engines, the number of regular firemen—or, at least, the number in excess of one attendant—may be taken as proportional to the quantity of steam demanded when working at ordinary power, and with very large marine engines the same remark may sometimes apply to engine-room attendance.

In recapitulation:

(1) In working up this account it will be most convenient, as will be presently seen, to refer all costs to volume of cylinder, and to so express variable quantities that they may enter our equations in terms of the ratio of expansion, which ratio is to

be taken as hereafter shown, as an independent variable upon which all other variable quantities are made dependent. We will enter all constant quantities as so many dollars of *annual* expense; the total, invariable expense will then be A', where A' includes all such expenses, whether chargeable to the engines or boilers, or to both.

(2) The cost of an engine varies according to no definite rule, and differs greatly with type of engine, kind of valve gear, character of work and value of material and labor, both at the manufactory and at the place of installation. With certain standard forms of engine, if large, it is found that the cost to the builder may be reckoned as very nearly proportional to volume of steam-cylinder, and his prices may be fixed on that basis. The cost of transportation, other things being equal, may often be similarly estimated, as may expenditures for repairs, engineer's supplies, etc., although these items are less exactly determinable.

It is here assumed that interest on cost of engine in place, depreciation, repairs, and all other expenses variable with size of engine, are to be reckoned per cubic foot of cylinder. This method is, in the opinion of the writer, more nearly correct than any other system of charging to this account that he has considered, and its probable error will be certainly unimportant for the small range met with in the usual case here studied.

(3) The cost of steam supplied to the engine, exclusive of the constant quantity entered in (1) may be safely reckoned as a certain number of dollars per pound or per cubic foot of steam worked in the cylinder.

The weight of steam supplied for the performance of work—when the weight per cubic foot of steam at the given pressure, p, is w, and its volume is $v_1 = v_2 \div r$—where r is the "real" ratio of expansion, is $w\,v_1 = \frac{w\,v_2}{r}$; its cost per cubic foot of steam cylinder is $\frac{k\,w\,v_1}{v_2} = \frac{k\,w}{r}$, and its total cost per year is $2\,R\,k\,w\,v_1 = 2\,R\,k\,\frac{w\,v_2}{r}$ where R is the number of revolutions made by the engine per annum.

To this weight is to be added steam wasted by cylinder condensation, leakage, and by conduction and radiation from engine and boiler. This last quantity varies greatly with kind of engine, speed of piston, and other circumstances more or less

under control of the builder or engineer. It sometimes even amounts to several times as much as the steam actually utilized.

It may be allowed for by multiplying the last item by a factor greater than unity.

5. *Theory of the Efficiencies of the Perfect Ideal Steam-Engine.*

When, as is perhaps sometimes allowable, if treating of the best of modern engines, the variation of cylinder condensation with variation of the ratio of expansion may be neglected, the "EQUATION OF IDEAL STEAM-ENGINE EFFICIENCIES," as the writer would call it, may be written:

$$C = \frac{1}{E^{\text{iii}}} = \frac{A\,r\,v_1 + B\,v_1}{2\,R\,W_n} = \frac{A + B\,r^{-1}}{2\,R\left(p_1\dfrac{n r^1 - r^{-n}}{n-1} - p_b\right)}$$

where C is the counter efficiency, and E^{iii} is the ratio of work done to variable costs, and therefore in the sense adopted here, the efficiency. This becomes a minimum, and the best ratio of expansion is obtained when, r being made the independent variable,

$$A\,p_1\frac{n - n\,r^{1-n}}{n-1} - B\,(p_1\,r^{-n} - p_b) = 0\,;\ r^{-n} - M\frac{n - n\,r^{1-n}}{n-1} = \frac{p_b}{p_1}$$

Here r has become r_e^{iii}. In these equations A is the total annual variable charge per cubic foot of cylinder on engine account, B is the annual cost of steam per cubic foot *filled* each stroke, and is measured by $2\,R\,w\,k$, when R is the number of revolutions of engine *per annum*, w the weight of a cubic foot of steam at the pressure p_1, and k its cost per pound, including all running expenses, in the boiler-room, and $M = \dfrac{A}{B}$.

More explicitly: since this problem demands minimum cost of a known power and the Ratio of Expansion at Maximum Commercial Efficiency, we have

$$p_1 v_1\frac{n - r^{1-n}}{n-1} - p_b r v_1 = \text{Constant} = W.$$

The variable cost will be, as before,

$$K = A r v_1 + B v_1,$$

which is to be a minimum. But, from the equation of condition, above,

$$v_1 = \frac{W}{p_1 \frac{n - r^{1-n}}{n-1} - p_b r}.$$

Thence

$$u = \frac{M + r^{-1}}{nr^{-1} - r^{-n} - \frac{p_b}{p_1}(n-1)};$$

and the minimum is found, as above, when $\frac{du}{dr} = 0$; *i. e.*, when

$$r^{-n} - M\frac{n - nr^{1-n}}{n-1} = \frac{p_b}{p_1}.$$

The construction of the equation shows that, under the assumed conditions, this ratio of maximum commercial economy is not dependent on the size of engine; but small engines have a higher value of p_b than large engines; they are usually more subject to cylinder condensation, and have greater back pressure and friction; they therefore require to be worked with somewhat less expansion than large engines.

Thus the solution of the problem determining the ratio of expansion r_e^{iii} at "Maximum Commercial Efficiency," or Efficiency of Capital, fixes that size of engine which, doing the required work, will do it at least cost. The sum of all variable expenses being here made a minimum, the total running expense, which includes all variable charges, also becomes the least possible, and the given work is done at least total annual cost.

To find the ratio of expansion at which a given engine will give the largest amount of work for the dollar, *i. e.*, to determine the "Ratio of Expansion r_e^{iv} at Maximum Commercial Efficiency of a Given Plant," we may use this same general equation. In this case, the size of the engine being fixed, the annual "cost of engine" becomes constant, and we write the equation in precisely the same form as before.

$$C = \frac{1}{E^{\text{iv}}} = \frac{A_1 r v_1 + Bv_1}{2 R W_n}$$

making the symbol A_1 cover all annual expenses of the engine-room, estimated per cubic foot of cylinder, including all the *con-*

stant charges of attendance in the boiler-room as well, while B only includes costs variable with the steam supply; C thus measures the ratio of total annual expenses of operation to work done. We thus obtain such a ratio of expansion that

$$r^{-n} - N \frac{n - n\, r^{1-n}}{n - 1} = \frac{p_b}{p_1}$$

when N is the ratio of the total expenses classed with engine cost to the "cost of full steam," as already taken, and r has become r_e^{iv}.

Again: making A and N equal zero in the general equation, and making p_b the sum of all useless resistances

$$r^{-n} = \frac{p_b}{p_1}$$

and $r = r_e^{ii}$, the ratio of expansion at "Maximum Efficiency of Engine."

Similarly, if p_3 is the back pressure in the steam cylinder

$$r^{-n} = \frac{p_3}{p_1}$$

and we have the ratio of expansion at "maximum efficiency of fluid," $r = r_e^{i}$.

In each case, the expression obtained is derived, it will be noted, by making r the independent variable, and the first is independent of the actual size of the engine. Thus we determine, in each case, that ratio of efficiency which is correct under the assumed conditions for all engines of the class upon which our estimates are based.

We thus are able to *tabulate* the proper size of engine for assumed quantities of work, and the powers at which each engine, once set, will work with maximum efficiency, commercial or other, if the power can be utilized. Finally, comparing costs, it can be determined in any known case just when a change of engine will be financially advisable. But the above simple and beautiful method of treatment cannot be applied where cylinder condensation becomes a serious item; in fact, therefore, it is comparatively valueless for nearly all cases which arise in engineering practice.

A comparison of the quantities of steam demanded to supply an engine thermodynamically "perfect" with the actual quanti-

ties required by even the best engines exhibits so wide a difference that it becomes obvious that the determination of the efficiency of an engine and the solution of the questions involving those of expenditure of heat are not problems in thermodynamics simply. The mathematical theory of the steam-engine is not yet in so satisfactory a state—and cannot be until the correct theory of this transfer of waste heat can be introduced into it—that the engineer can often use it in everyday office-work with much confidence, unless checked by direct experiment. Even where algebraic analysis is probably capable of giving approximate results, few engineers will attempt to use it. For the last case, however, Rankine's graphical treatment of the problem here studied is conveniently applicable, and by its use the engineer may easily solve such problems by a simple construction on his drawing-board.

6. *Rankine's Diagram of Efficiency.*

In illustration : Suppose an engine, of one cubic foot capacity, in operation, expanding steam adiabatically, its cylinder and piston being perfectly impervious to heat, and having an "adjustable" expansion gear. When following full stroke it uses one cubic foot of steam per stroke, at initial pressure ; when "cutting off" at half stroke, one-half cubic foot, and at a cut-off of one-quarter, one-fourth of a foot, is used. The quantity used is always inversely as the ratio of expansion. To determine the best ratio of expansion : Construct a curve, *O A* (Fig. 36), of which the abscissas *O X* are proportional to the amount of steam used, while the ordinates parallel to *O Y* are proportional to the absolute mean pressure for that degree of expansion, and therefore to the "total work" done by the steam so measured off. Drawing a line, *B C*, parallel to the base, and at a height proportional to the back pressure in the engine cylinder, the ordinates measured from any point in the curve down to this line will measure the "effective pressure" shown by the indicator, and will be proportional to the "indicated power" of the engine. Again : Drawing a line, *D E*, at the height measuring the sum of all useless resistances, the "net" or "dynamometric" power of the engine, as transmitted to the machinery of transmission, is measured by this line. Finally, extending this second line toward the left, and measuring off upon it a distance proportional to the cost of operation, so far as it varies with changes

in plant, and measured on the same scale as is used in laying off the base line in terms of cost of steam, the sum of the two costs, *G F*, measures the total variable expense of obtaining the power, while the height of ordinate *G H*, measured from the last drawn line, is proportional to the amount of power obtained. For any one point, *F*, the straight line *F H*, drawn just

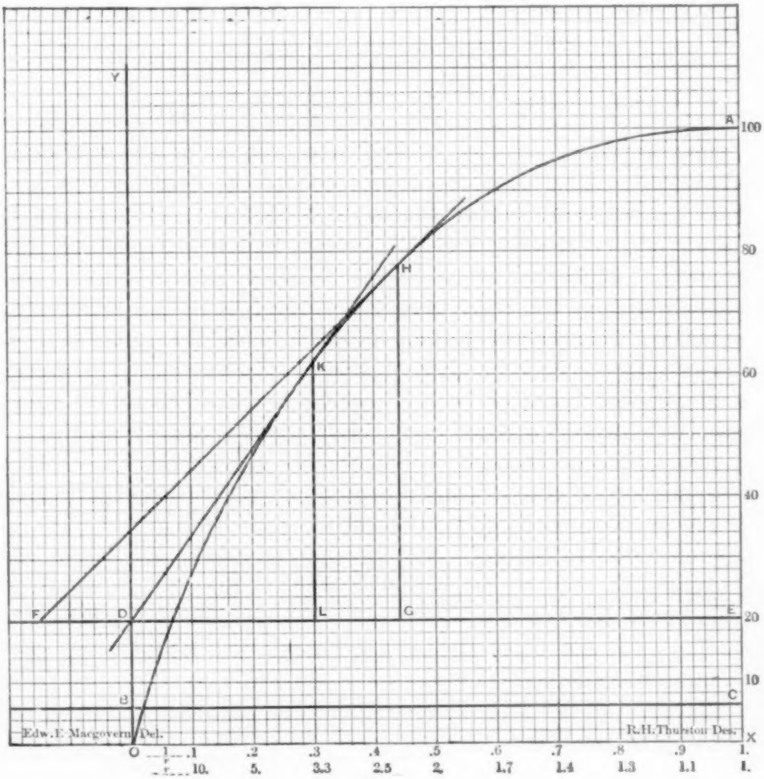

Fig. 36.

tangent to the curve, touches the latter at a point marking the ratio of expansion at maximum commercial economy, or if drawn from the axis *O Y*, as *D K*, identifies the ratio for maximum "efficiency of engine" as that term is technically applied.

This simple construction is correct and exact only when cylinder condensation may be neglected. It has been applied by Rankine to the case of the Cornish Engine, which—because of its effective steam jacketing, singular steam distribution, and

the peculiar rapidity with which the piston, on the "in-door" stroke, jumps from one end of the cylinder to the other—is usually less affected by that most serious of losses, than is almost any other known form of engine. For other forms of engine this construction leads to results that are often, as will be seen presently, widely inaccurate. It has become perfectly obvious that any method to be accurate and reliable must take account of *all* losses of heat of large amount, and must distinguish between efficient and inefficient classes of heat engines.

7. *Theory of Efficiencies of Real Engines.*

The direct process of analytical treatment of this General Problem for Real Engines, as adopted by the writer, is the following: Let it be known what style of engine is to be adopted for any case and what kinds of boilers and attachments are to be used in supplying steam; let the costs of attendance and all other expenses be ascertainable. Then, to adopt Rankine's terms, determine A, the annual variable "cost of engine" of the selected type, per cubic foot of steam cylinder, and B, the annual variable "cost of boiler," per cubic foot of steam cylinder supplied without expansion and without allowance for cylinder condensation or leakage; ascertain all other costs, invariable with change of size of either engine or boiler within the range of the problem, and call their total C.

The "cost of engine" will be $A v_2 = A r v_1$; the "cost of boiler" will be $B v_1$ and the constant charges D. Make $\frac{A}{B} = M$.

The work done per stroke may be called W_n, and work per annum becomes $2 R W_n$.

The ratio of the total of annual variable cost of power to work done by the engine is:

$$u = \frac{A r v_1 + B v_1}{2 R W_n} = \frac{A v_2 + B v_2 r^{-1}}{2 R W_n}$$

which is a minimum when $\frac{M + r^{-1}}{W_n}$ is a minimum.

This value of W_n may be obtained by multiplying the value of W_n for adiabatic expansion, such as would be obtained in a non-conducting cylinder by a factor less than unity variable with the ratio of expansion, as has been shown in the preceding paper,

which shall measure the ratio of actual work done in the metal cylinder to that done in adiabatic expansion. Thus:

Let b represent the proportion of steam present in the working fluid when $r = 1$, as determined by the amount of cylinder condensation; let r^q represent the rate of variation of losses with increase of the ratio of expansion, and let n be the index for the actual expansion line of the mixture, to be determined, if possible, by experiment.

Then we shall have: $W_n = 2\,R\left(b\,p_1 v_2 \dfrac{n\,r^{-1} - r^{-n}}{n-1}\,r^q - p_b\,v_2\right)$.

THE "GENERAL EQUATION OF ALL STEAM-ENGINE EFFICIENCIES," therefore, is

$$C = \frac{1}{E^{\text{iii}}} = \frac{A\,v_2 + B\,v_2\,r^{-1}}{2\,R\left(b\,p_1\,v_2 \dfrac{n\,r^{-1} - r^{-n}}{n-1}\,r^q - p_b\,v_2\right)} \qquad \text{(A)}$$

which becomes a minimum and makes the *Commercial Efficiency* of an engine doing the required work a maximum when, to obtain r_c^{iii}, we have made

$$r^q + \frac{q}{M(q-1)}\,r^{q-1} - \frac{q-n}{n(q-1)}\,r^{q-n+1} -$$

$$\frac{q-n+1}{Mn(q-1)}\,r^{q-n} = \frac{n-1}{Mnb(q-1)}\,\frac{p_b}{p_1} \qquad \text{(B)}$$

When the ratio of expansion, r_e^{iv}, at "*Maximum Efficiency of a Fixed Plant*" is required, $A^v{}_2$ is constant, and we may make

$$\frac{A + \dfrac{D}{v_2}}{B} = N$$ and the equation of *Efficiency of Plant*

$$C = \frac{1}{E^{\text{iv}}} = \frac{N + r^{-1}}{2B^{-1}R\left(bp_1v_2 \dfrac{nr^{-1} - r^{-n}}{n-1}\,r^q - p_bv_2\right)} \qquad \text{(C)}$$

gives, similarly, for r^{iv} and a maximum,

$$r^q + \frac{q}{N(q-1)}\,r^{q-1} - \frac{q-n}{n(q-1)}\,r^{q-n+1} - \frac{q-n+1}{Nn(q-1)}\,r^{q-n} =$$

$$\frac{n-1}{Nnb(q-1)}\,\frac{p_b}{p_1} \qquad \text{(D)}$$

To obtain r_e^{ii} for *Maximum Efficiency of Engine*, we make $N = 0$ and have

$$r^{q-1} - \frac{q-n+1}{nq} r^{q-n} = \frac{n-1}{nbp} \frac{p_b}{p_1} \qquad \text{(E)}$$

and to obtain *Maximum Efficiency of Fluid*, p_b becomes p_3 and

$$r^{q-1} - \frac{q-n+1}{nq} r^{q-n} = \frac{n-1}{nbq} \frac{p_3}{p_1} \qquad \text{(F)}$$

in which r_e^{i} satisfies the equation.

When $b = 1$ and $q = 0$, we have the *ideal* case considered in § 5, and the equation (B) for r_e^{iii} becomes, as before, for the per. fect engine:

$$r^{-n} = M \frac{n - n^{1-n}}{n-1} = \frac{p_b}{p_1} \qquad \text{(G)}$$

for Maximum Commercial Efficiency; and we again obtain for Maximum Economy of a Given Plant, for r_e^{iv},

$$r^{-n} - N \frac{n - nr^{1-n}}{n-1} = \frac{p_b}{p_1} \qquad \text{(H)}$$

For Maximum Efficiency of Engine, we again get a value of r_e^{ii}, such that

$$r^{-n} = \frac{p_b}{p_1} \qquad \text{(I)}$$

and finally for Maximum Efficiency of Fluid we find a value of r_e^{i}, such that

$$r^{-n} = \frac{p_3}{p_1} \qquad \text{(J)}$$

precisely as already stated in § 5.

The quantities of steam and of fuel used per hour and per horse-power in the non-conducting cylinder with and without expansion, and in the metal cylinder, with and without expansion, are as

$$1 : \frac{p_1}{p_m r} \text{ and } \frac{1}{br^{-q}} : \frac{p_1}{bp_m r^{q+1}} \, .$$

In general, where the Equation of the Curve of Efficiency is given, we shall have at Maximum Efficiency of Fluid

$$\frac{dy}{dx} = \frac{p_m - p_3}{p_1} br^{q+1};$$

at Maximum Efficiency of Engine,

$$\frac{dy}{dx} = \frac{p_m - p_b}{p_1} br^{q+1};$$

at Maximum Efficiency of Plant,

$$\frac{dy}{dx} = \frac{p_m - p_b}{1 + Nbr^{q+1}} \cdot \frac{br^{q+1}}{p_1},$$

and at Maximum Efficiency of Capital,

$$\frac{dy}{dx} = \frac{p_m - p_b}{1 + Mbr^{q+1}} \cdot \frac{br^{q+1}}{p_1};$$

for cases met with in practice; while the purely thermodynamic treatment gives

$$\frac{dy}{dx} = \frac{p_m - p_3}{p_1} r; \quad \frac{dy}{dx} = \frac{p_m - p_b}{p_1} r;$$

$$\frac{dy}{dx} = \frac{(p_m - p_b)r}{p_1(1 + Nr)}; \quad \frac{dy}{dx} = \frac{(p_m - p_p)r}{p_1(1 + Mr)}$$

for these several cases for the perfect engine.

For the *ideal* case, x and y being the co-ordinates, the equation of the Curve of Efficiency gives

$$\frac{y}{x} = \frac{p_m}{p_1} \div \frac{1}{r} = \frac{n - r^{1-n}}{n - 1}.$$

For the real engine,

$$\frac{y}{x} = \frac{p_m}{p_1} \div \frac{1}{br^{q+1}} = b^2 r^{2q} \frac{n - r^{1-n}}{n - 1}.$$

It will be remembered that ordinates represent the work done by the quantities of steam measured by the corresponding abscissas.

The constants in these formulas should be carefully determined, if possible, by experiment on the class of engine to be

designed; but, in the absence of better data, are taken by the writer, when designed, as follows, for good practice:

	b.	q.	n.
I. Cylinders jacketed, steam superheated at boiler,	0.90	0.00	1.06
II. Cylinders jacketed, steam saturated, but dry at boiler, ...	0.88	—0.20	1.06
III. Cylinders unjacketed, steam saturated, but dry at boiler, ...	0.88	—0.25	0.99
IV. Cylinders unjacketed, steam wet, . . .	0.85	—0.30	0.98

n is the exponent of the probable actual curve.

Case I. is illustrated by the best work yet done by Corliss, Leavitt and Cowper. The value of b is obtained by comparing the actual results of test with the figures for the perfect engine to determine the waste; that of n is obtained by consideration of the fact that in these engines, when effectively jacketed, the steam is retained just dry and saturated during the stroke, and q is taken to be 0, since the rate of transfer of heat to exhaust is nearly constant for such engines so far as known, and is of minimum amount. The values for Case II. are obtained by examining scattered records of somewhat less efficient engines. The values of b and q for Case III. are obtained by studying the performance of good unjacketed engines; while those for the last, Case IV., came originally from the results of test of the United States steamer *Michigan*, with an allowance of ten per cent. for the unrecorded waste concealed by re-evaporation.

8. *Curve of Efficiency for Real Engines.*

The correct curve for the diagram, as has been seen, is neither that due to diabatic nor that given by isothermal expansion, nor is it any known intermediate curve; it has not as yet been expressed by any exact equation.* It is never the curve of mean pressures, obtained on the assumption of any yet classified method of expansion, and rarely approximates to either of the ideal engine curves. It is very variable in location, in form, and in dimensions, and, as yet, can only be determined by experiment.

In the diagram above given, it is thus evident, the quantities

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* An inspection of these curves would indicate that the equation, $y = ae^{-brc}$ may be more exact than the more manageable forms used by the writer. The general character of these curves was first pointed out by him in debate at the meeting of the Am. Soc. Mech. Engrs., May, 1881.

of steam laid down in arithmetical progression on the base line cannot now correspond with the ratios of expansion there taken; since in actual engines those values are not in exact, or in constant, inverse proportion. The quantity of steam drawn from the boiler is not measured by the volume of cylinder open to steam up to the point of cut-off; nor is the mean pressure obtained with any given weight of steam drawn from the boiler at each stroke, even approximately, equal to that given by adiabatic expansion in a non-conducting cylinder. Both these variations operate to depress and flatten the Curve of Efficiency on the diagram, and thus often to reduce the ratio of economical expansion far below that predicted when the former and impossible conditions were assumed. The vertical scale of pressures and the horizontal scale of ratios of expansion have become altered in relative magnitude, and the latter becomes for usual cases a variable scale.

To obtain a solution of the actual problem as presented daily to the designing engineer, a new method of procedure must be adopted. The writer proposes the following, as simple in principle, easy of application, and especially as giving, from the use of experimentally derived data, results which may be received with confidence and used for any engine falling into the class of typical cases studied.

9. *Thurston's Diagram and Curve of Efficiency.*

It has become evident that the best ratio of expansion or proper "point of cut-off" for any actual case is determined, not by the percentage of loss sustained at that point simply, or by the cylinder condensation there taking place, but by the *method of variation* of such loss, not only at that point, but all along the curve of efficiency and at other ratios of expansion; for, in the metallic cylinder, the proportion of the water present in the working fluid is constantly varying with change of volume, and the loss of pressure and of work is constantly and proportionally varying, producing a curve of efficiency differing greatly in character, form, and location from that given by a non-conducting cylinder.

This "Curve of Efficiency," as discovered by the writer, and first described in the paper already referred to, is, therefore, a curve of peculiar character and essentially different from the line of mean pressures used by Rankine. It is obtained thus:

Assume for the unit of measure so much steam as is drawn from the boiler at one stroke of piston, without expansion or condensation; draw OX (Fig. 37) and divide it as unity of volume or of weight into a scale of equal fractional parts which are to be laid down on both sides of O. Erect at X a perpendicular, XBA, and divide it into any convenient number, say 100, of equal parts. Were there no condensation, the fluid being worked

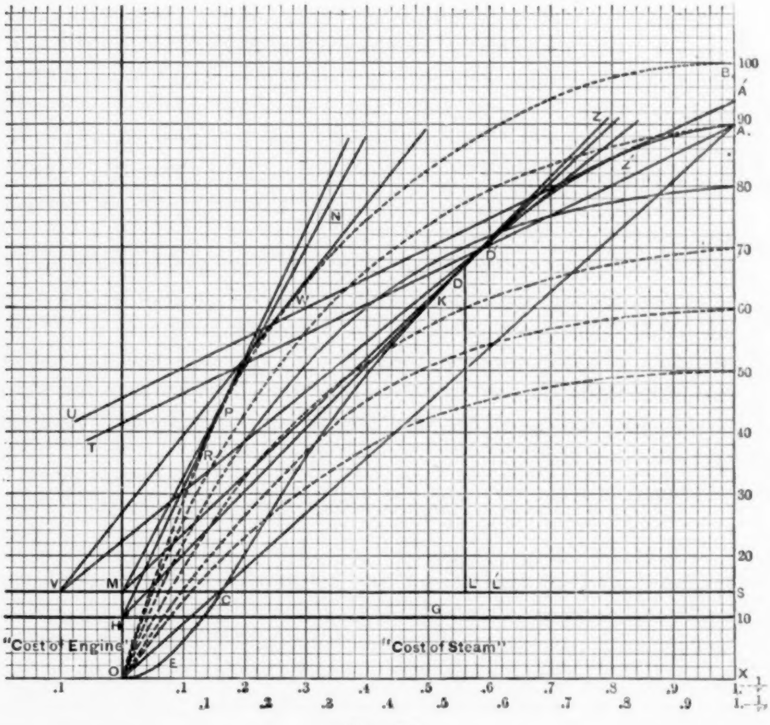


Fig. 37.

in a vessel of non-conducting material, instead of an iron steam-cylinder, the mean pressure at full stroke and the work done per cubic foot or per pound of boiler steam would be measured by XB, and the curve of mean total pressure or of steam used per "total" horse-power per hour would be OWB.

Condensation reduces the work at full stroke, and it is actually measured by XA. Were the condensation in constant proportion for all values of the real ratio of expansion, the ordinates of the true curve would be proportional to those of OB, and the

values of $\frac{1}{r}$ would remain proportional to the expenditure of steam as in adiabatic expansion. But the amount of condensation usually increases, and often very rapidly, with increasing expansion; and at one-half, one-quarter, or one-eighth cut-off, more, and sometimes much more, than one-half, one-quarter, or one-eighth as much steam is used as at full stroke. The scale of ratios, $\frac{1}{r}$, is thus not only shifted but is made a scale of unequal parts, of which the successive values must be located by determining the amount of steam used at each point of cut-off, and placing the value $\frac{1}{r}$ opposite the value of the corresponding amount of steam expended, as has been done in Fig. 37, along the scale $\frac{1}{r}$.

If, as is sometimes nearly true, the losses by condensation and leakage, or both, are so great as to annul the benefit derived from expansion, the curve flattens down to a straight line, *OA*. In every engine a point is reached by increasing r at which the amount of steam used per hour per total horse-power is as great as at full stroke; in every case, therefore, the true curve crosses the line *OA*, as at *C*. In every unjacketed, and perhaps in jacketed engines, a point is reached before the curve terminates at *O*, at which the ratio of expansion becomes so large, the expenditure of steam so small and losses so great, that the curve falls nearly to the axis *OX*; thus, instead of crossing *OX*, it has a point of contrary flexure between *C* and *O*. The line *OEC DA* is thus representative of the class of mean pressure or efficiency curves given by actual engines. Could the variation of expenditure of heat be exactly expressed by an algebraic equation, this equation would be that of the line *ACEO*, and the problem would be capable of exact solution by algebraic methods.

Another, and, in some respects, more readily understood, although less exact, method of constructing the curve of efficiency is to make the base scale a uniform scale *both* of steam consumption and of cut-off, as for adiabatic expansion, and then to make the ordinate, at any point, proportional to the quantity of work done at the given point of cut-off by the quantity of steam there measured, as was done in the preceding paper.

10. *Solution of Problems of Efficiency for Actual Engines.*

Draw HG at a height above OX equal to the back pressure, p_3; then the tangent line HK identifies a point K, which gives the ratio of expansion at *maximum efficiency of fluid*—since the ordinate GK measures the work done by the steam drawn from the boiler—and the ratio $\frac{GK}{HG}$ becomes a maximum at K. Drawing ML to represent the pressure demanded to overcome all useless resistance, $p_b = p_3 + p_f$, a similar construction identifies D as the point corresponding to the ratio of expansion at *maximum efficiency of engine.* Finally, extending this line to V and making VM proportional to cost of all variable running expenses, stated in terms of cost of steam per cubic foot of cylinder, $VM = \frac{A'}{B} = M$, when working at full stroke, the tangent line VZ meets the curve at a point near D', which gives the ratio of expansion at *maximum commercial efficiency.* Comparing these values of r with those given by the tangents, HR, MP, VW, drawn to the curve OB, for dry saturated steam, expanded adiabatically, it is seen that the best ratio of expansion must be, in each actual example, less than in the hypothetical case, and may even become unity for each kind of *efficiency*, with very slow piston speed, where, were no loss of heat to occur in the manner here considered, considerable expansion would be desirable. These differences all become greater as the back pressures and current expenditures become less.

Making the value of VM a measure of the total current expenses, including the constant as well as variable items of cost of attendance, as those of rent, insurance, etc., which do not depend on size of engine, $VM = \frac{A'}{B} = N$, a value of r will be obtained which is that real ratio of expansion at which *maximum work is done for a given expenditure*, per hour or per annum, on a plant actually established. This problem is less frequently presented to the engineer than those already given, and is not the problem of maximum commercial efficiency; since this ratio and the corresponding power of engine being determined, it will be found on solving for maximum commercial efficiency that another proportion of engine with higher ratio of expansion will supply the power now demanded, at still lower cost. To this

latter engine the last problem again applies. The practical conclusion to be drawn from the solution of the interminable succession of problems of this last character, which thus follow the first, is that the largest amount of power possible should be intrusted to a single engineer or crew of attendants, and placed under one roof, etc.

Finally, the last of the problems enumerated at the beginning of this paper may be solved with equal ease.

To ascertain just what ratio of expansion and what amount of work, as a maximum, can be profitably obtained from an established plant, calculate the net power obtainable from the engine without expansion, and the market value, or otherwise real value to the proprietor, of that power, and estimate, also, the cost of fuel and all items of cost variable therewith. Divide the price of power by this cost. Then lay off, on the base line appropriate to the given engine, the distance SV, produced, equal to the quotient, taking the distance MS as unity, and from the extremity of this base line draw a straight line TA, to the point A, at the altitude AS equal to the measure of the net power just calculated. Finally, draw a line UA, parallel to this hypothenuse of the triangle so described, and tangent, as at Z', to the curve of efficiency. The point of tangency Z' will identify the *minimum profitable ratio of expansion* and determine the maximum amount of work obtainable from this engine with profit. For, at this point of tangency the ratio of total cost of power to the price obtainable for it, or to its actual value, is that already given as the greatest permitting a fair profit, while the ratio of expansion so determined is that giving that power at that rate of cost.

The value of the *Ratio of Expansion at Maximum Profitable Power* is evidently, in all actual examples, less, and the work done is greater, than in either of the preceding cases, and *is dependent upon the market value of that power.*

In all cases, the ratio of expansion calculated is the real ratio; the apparent ratio is decreased by clearance, and increased, often considerably, by the wiredrawing which occurs just before the valve is seated. It is evident that loss of steam by leakage modifies the curve of efficiency in the same general way as loss of heat by cylinder condensation.

Section 2. Applications and Deductions.

11. *Method of Construction of the Diagram of Efficiencies.*

By the application of this method, as proposed by the writer, we may thus determine, from the results of experiment, a set of data and a graphical representation of those results which may serve as a standard for the class to which the engine examined belongs.

It is further evident that, the ratio of expansion at maximum efficiency being determined by experiment and with precision by this graphical method, it becomes easy to ascertain with exactness the value of the ratio of expansion at maximum commercial economy.

The base line, VL, for maximum efficiency of engine being fixed, the position of the point V on that line is readily obtained, and thus the line VZ becomes known, and the ratio of expansion at maximum commercial economy is determined. Similarly, by extending the line VL until it becomes proportional to the sum of all costs, constant and variable, the ratio of expansion giving maximum work per dollar expended with the given engine, may, if desired, be found.

The accompanying plate (Fig. 38) represents a series of real Curves of Efficiency, several of which are given by working engines. Such curves are here, for the first time, presented.

The straight line $A_1 A$, for the case in which $[n = (-1)]$ is the line of Constant Efficiency obtained in an assumed case of no gain and no variation of efficiency with increasing expansion from $r = o$ to $r = \infty$.

The curve marked G, and dotted, is the standard Curve of Efficiency for adiabatic expansion of steam containing initially ten per cent. water ($n = 1.125$).

The line F is the Curve of Mean Pressure or of Efficiency for steam initially dry ($n = 1.135$).

The other curves are all obtained by reference to experiments on various classes of engines. B is the Curve of Efficiency for the common marine, unjacketed, single cylinder, condensing engine; C is the Curve of Efficiency for the same engine using superheated steam; D is that of a "compound" jacketed, condensing, marine engine; E applies almost exactly to both non-condensing engines and compound engines of the best classes,

and the curve F is practically correct for the last-named class of engines when the steam is kept thoroughly dry by effective superheating and reheating in a receiver.

Curve B is thus obtained:

Collating Isherwood's with other experiments made for the United States Navy Department, which are almost the only valuable experiments for our present purpose ever made on this class of engine as used on our river steamboats and in the Naval Service,* we find the following relative measures of steam consumption at various ratios of expansion, and of work done by it.

Cut-off $\frac{1}{r}$ (real), ...	.1	.3	.5	.7	.9	1.00
" $\frac{1}{r^1}$ (apparent), . . .	.05	.25	.47	.68	.89	1.00
Relative weights of steam .	.16	.41	.60	.76	.92	1.00
" " total work " done,	.21	.56	.82	.97	1.00	1.00

The base line, B, for this case, in which $\frac{p_b}{p_1} = \frac{1}{8}$, is drawn on the plate, and on this line are a set of values of $\frac{1}{r}$ corresponding to the relative weights of steam as laid down on the bottom scale, .10 above .16, .30 above .41, etc., etc., and the ordinates erected at these points are made proportional to the total work done at those ratios of expansion; and, thus carefully laying down these points, the line B_1 B is constructed as the Curve of Efficiency for the engine, of which those of the United States steamers "Eutaw," "Michigan," and all "American River Steamboat Engines" are representatives.

In a similar manner, by collating the data obtained by the trial of the "Georgiana's" engine, using superheated steam, with the experiments of Hirn showing a reduction of exhaust waste by superheating, we obtain the Curve of Efficiency C_1 C, and the Base Scale accompanying it.

A set of experiments on the "Bache" gives the line D_1 D, and the curve E_1 E is found, by trial, to meet cases of good work with non-condensing engines, unjacketed, but worked at high piston-speed, and of some of the very best results obtained with compound engines of the most successful types.

* "Researches in Engineering," vol. ii.; table, p. xxxiv.

Curve F seems to meet those cases in which superheating has been so efficient as nearly to prevent all condensation, and the line corresponds closely with the adiabatic for steam, dry initially, and only condensing so much as is due to the performance of work.

The location of these lines, as well as their form, is evidently variable with every change affecting efficiency.

The writer has been unable to find sufficiently complete series of experiments reported, to construct these last curves as exactly and satisfactorily as the first, and has been compelled to work from scattered and comparatively incomplete data. The results, so far as comparable with practice, seem to indicate sufficient accuracy to have been obtained for such illustration as is here necessary; but extended experiments on the more modern engine —like those experiments for which we are indebted to Isherwood, on earlier forms—are much needed. Even curve B is not as far removed as it should be from the adiabatic curve, since it is constructed on the assumption that re-evaporation could be neglected in the case studied, an inexact assumption, but one made necessary by the absence of data relating to condensation at the point of cut-off. The writer would be inclined to increase the proportion of loss taken from the record by at least an additional 10 per cent., making the total, probably, equal to

$$h_c = 0.2 \sqrt{r} \text{ nearly.}$$

To obtain an exact solution of these problems, the quantity of steam present in the cylinder *at the point of cut-off* must be precisely measured and compared with the quantity sent to the engine from the boiler. This absolutely essential comparison has been very rarely made by engineers conducting trials of steam-engines.*

* In fact, the only nearly complete sets of essential data given on any engines are those published in reports of United States Naval Engineers and by Hirn. Investigators have not yet learned the importance of ascertaining, in every engine trial, the weight of water passing through the engine, and of comparing it with the weight of steam present *at each point* of the stroke as measured by the indicator. Where experiments, otherwise valuable, have been made, it has rarely occurred that any one set of conditions has been preserved constant, while observing other variables, so as to secure any useful data for investigations like the present. Professor Cotterill's treatment should be applied in every case to secure a full and satisfactorily valuable set of data.

12. *Mode of Application of the Method and Use of the Diagram.*

Comparing curves F and G, representing the case of steam expanding in a non-conducting cylinder, *i. e.*, adiabatically, with the other curves, obtained for expansion in real engines, it is seen, at a glance, that the more perfectly exhaust-waste by cylinder condensation is guarded against, the more closely does the actual engine approach to the perfect engine in its utilization of steam, and the less effective the provision against such loss the more widely does the Curve of Efficiency depart both in location and form from the ideal curve, finally approximating to the straight line of Constant Efficiency A_1 A. While the best engines approach comparatively near the curve of maximum possible efficiency, the great majority of condensing engines in use are of the class represented by that giving Curve B, which latter is, however, by no means a case of remarkably low efficiency. In many cases the curve will be found to fall within the line B.

Selecting one of these curves, as B, or C, we may solve either or all of the problems already defined by merely applying a straight-edge to the diagram. For B we have $p = 40$; $p_b = 5$; $\frac{p_b}{p_1} = \frac{1}{8} = 0.25$. To determine the Ratio of Expansion at Maximum Efficiency, draw the base-line at the altitude 0.125, and from its junction with the ordinate at the zero point, draw the line HI tangent to the curve ; it touches the curve at I, and the corresponding ratio of expansion on the base-line beneath is a trifle less than $\frac{1}{r} = 0.4$; $r = 2.5$ nearly—a result confirmed by reference to the original data.

Next, ascertain the hourly or annual cost of supplying the engine with steam worked without expansion or cylinder condensation, including all items of expense variable with the quantity of steam used, and determine the *variable* part of all running expenses in the engine-room, including interest, insurance, rent, cost of oil, and so much of the wages of the attendants as is properly taken as variable with the size of the engine. Suppose, as in a case taken by the writer, that the latter is found to be two per cent. of the former, $M = 0.02$.

From the point T, at the ordinate 0.02, on the left of the H, draw the tangent to the curve as TL on the curve B; its point

of tangency identifies the best ratio of expansion for commercial efficiency.

Similarly compare the "cost of full steam" with the sum of all other running expenses chargeable to the plant; if the ratio is $N = .04$, draw the tangent line WL from the ordinate .04 and thus find that ratio of expansion which will give most work for the money expended on a plant already installed. The lines PQ, RV and SU thus determine these three ratios for the curve F, of a well-constructed non-condensing engine, using perfectly dry steam and with a ratio $\frac{p_b}{p_1} = 0.20$. The line NM determines the ratio of expansion at maximum efficiency for the case D, a compound engine doing good work with $\frac{p_b}{p_1} = 0.05$.

13. *Estimation of Expenses.*

The following example illustrates, in detail, the calculation of M and N:

Rated power of given engine and boiler, . . .	500 H.P.
Working time, per annum, ...	3,000 hrs.

(*A.*) *Cost of Engine* (*variable with size of engine*).

Cost of engine, ...		$10,000
Annual interest at 6 per cent., ...	$600	
" cost of repairs and depreciation, 4 per cent., . .	400	
" materials used, ...	50	
Total annual cost, ...	$1,050	

(*B.*) *Cost of Boiler* (*variable with demanded boiler-power*).

Cost of boiler: actual, $12,000; for "full steam," . . .		$24,000
Interest on cost, using steam without expansion, at 6 per cent.	$1,440	
Repairs and depreciation, at 15 per cent., ...	3,600	
Minor expenses per annum, ...	200	
Total annual maximum cost, ...	$5,240	

(*C.*) *Fuel Account* (*variable with size of boiler*).

Coal, per year at the rated power, ...		2,000 T
" " with no expansion, ...		4,000 T
Cost of fuel at "full steam," at $5 per T, ...	$20,000	
" " transportation and storage at 50 c., . .	2,000	
Total maximum per year, ...		$22,000

(*D*.) *Attendance* (*wholly or partly constant or variable*).

(*a*) Engine-driver's (engineer's) pay per year, . .	$1,000
(*b*) Fireman's (stoker's) pay, per year ("full steam"), .	1,200
	$2,200

(*E*.) *Incidentals* (*constant as a rule*).

Rents, taxes, insurance, etc. per annum, . . .	$1,000

Studying the statement of costs, the mechanical engineer decides in each case, and for each problem presented, how the items should be grouped. For the case of a stationary steam-engine such as is here presented, he would find:

$$M = \frac{(A)}{(B) + (C)} = 0.035, \text{ nearly,}$$

if the costs (D_a), (D_b) are not variable within the probable range of variation; or

$$M = \frac{(A)}{(B) + (C) + (D_b)} = 0.03, \text{ nearly,}$$

if the cost of fire-room labor is variable with quantity of steam demanded. Then

$$N = \frac{(A) + (D) + (E)}{(B) + (C)} = 0.15, \text{ nearly,}$$

for the first case, and

$$N = \frac{(A) + (D_a) + (E)}{(B) + (C) + (D_b)} = 0.10, \text{ nearly,}$$

for the second case. In marine steam engineering, storage becomes an important matter, in items (A) and (D) and (B), as well as very important in (C) and (E), since every cubic foot occupied by machinery, fuel, or attendants displaces a cubic foot of paying loading. With very large powers, the items (D) both become to a certain extent variable, the one (D_a) with magnitude of the whole plant, the other (D_b) with quantity of fuel burned. Correctness in making up the bill of costs will be found to be absolutely essential.

14. *Statement of Results.*

Laying out these curves on a conveniently large scale and proceeding as just indicated, the writer obtained the results

exhibited in Table I, here given. Cases I to VI, inclusive, are obtained from Curve *E*; VII to XII from Curve *B*; XIII to XVIII from *E*, and XIX to XXIV from the best Curve of Efficiency, on the plate, Curve *F*.

The Ratio of Expansion at Maximum Efficiency of Fluid will be found in column r_e^{I}, that at Maximum Efficiency of Engine under r_e^{II}, and the best Ratio of Expansion for Commercial Efficiency, or for Maximum Efficiency of Capital, is given under r_e^{III}. *M*, *N*, are the ratios of cost. Comparing the first and especially the second set with the last, the enormous variation due to cylinder condensation is readily appreciated. Even the last case is far from the efficiency of the perfect engine.

The ratios of expansion for superheated steam in the unjacketed cylinder are obtainable from Curve *C*.

Table I.

Ratios of Expansion at Maximum Efficiency of Fluid of Engine and of Capital.

Single Cylinders.

Absolute Initial Pressures.			Case No.	Class I. Non-Condensing, High Speed.							Case No.	Class II. Condensing, Moderate Speed.						
P	P_m	Atmospheres.		p_3	p_b	M	$\frac{p_1}{p_b}$	r_e^{I}	r_e^{II}	r_e^{III}		p_3	p_b	M	$\frac{p_1}{p_b}$	r_e^{I}	r_e^{II}	r_e^{III}
40	2.8	$2\frac{2}{3}$	I	18	20	.02	2	2	2	2	VII	3	5	.04	8	$2\frac{1}{2}$	$2\frac{1}{4}$	2
60	4.2	4	II	18	20	.02	3	3	3	$2\frac{3}{4}$	VIII	3	5	.04	12	$3\frac{1}{2}$	$3\frac{1}{4}$	3
80	5.6	$5\frac{1}{3}$	III	18	20	.02	4	4	$3\frac{3}{4}$	$3\frac{1}{4}$	IX	3	5	.04	16	$4\frac{1}{4}$	4	$3\frac{1}{2}$
100	7.0	$6\frac{2}{3}$	IV	18	20	.02	5	5	$4\frac{1}{2}$	$3\frac{1}{2}$	X	3	5	.04	20	$4\frac{3}{4}$	$4\frac{1}{2}$	4
120	8.4	8	V	18	20	.02	6	6	$5\frac{1}{2}$	4	XI	3	5	.04	24	$5\frac{1}{2}$	5	$4\frac{1}{2}$
150	10.5	10	VI	18	20	.02	$7\frac{1}{2}$	7	6	$4\frac{1}{2}$	XII	3	5	.04	30	6	$5\frac{1}{4}$	5

COMPOUND, CONDENSING, JACKETED.

Absolute Initial Pressures.			Case No.	Class III. Saturated Steam.							Case No.	Class IV. Superheated Steam.						
p	p_m	Atmospheres.		p_3	p_b	M	$\frac{p_1}{p_b}$	$r_e^{\rm I}$	$r_e^{\rm II}$	$r_e^{\rm III}$		p_3	p_b	M	$\frac{p_1}{p_b}$	$r_e^{\rm I}$	$r_e^{\rm II}$	$r_e^{\rm III}$
40	2.8	2,	XIII	3	5½	.04	7	6	5	8	XIX	2½	5	.05	8	8	6	5
60	4.2	4	XIV	3	5½	.04	11	8	7	4½	XX	2½	5	.05	12	11	8	6
80	5.6	5⅓	XV	3	5½	.04	14	9	8	6	XXI	3	5½	.05	14	13	10	7
100	7.0	6⅔	XVI	3	6	.04	17	10	9	7	XXII	3	5½	.05	18	16	12	8
120	8.4	8	XVII	3	6	.04	20	11	10	8	XXIII	3	5½	.05	22	20	15	9
150	10.5	10	XVIII	3	6	.04	25	13	10	9	XXIV	3	6	.05	27	25	17	10

[p = Initial pressure measured from perfect vacuum; p_3 = Back Pressure in cylinder; p_b = same, including friction; M = Ratio of variable part of cost of engine to variable part of cost of steam, when $r = 1$, no cylinder condensation occurring.

$r_e^{\rm I}$, $r_e^{\rm II}$, $r_e^{\rm III}$ = Ratios of Expansion of Maximum Efficiency of Fluid, of Engine, and of Capital invested to obtain a Given Amount of Power with best engines of each class.]

The values here presented for the several cases are not to be taken by the engineer as exact for other examples. They are given as representative cases, and the engineer designing new engines should, whenever possible, construct his own diagram and make his own solution of the problem before him.

Further investigation will, undoubtedly, sooner or later, establish the Curves of Efficiency for those classes of engine and for those special cases for which the engineer can to-day only obtain them approximately. Meantime, the plate exhibits a range of variation of curve which extends completely across the field of every-day practice, and an experienced engineer can readily trust his judgment in the interpolation of the curve of efficiency for any special case arising in his own practice. For example: Cases of best practice in which the engine is worked at higher speed, and with a warmer condenser, and having less friction, will give a curve for the class from which B was obtained, which will fall between B and C.

The values given of $\frac{p_1}{p_b}$ are interesting in comparison with the values of r_e, as exhibiting this enormous difference between the best ratio of expansion in actual work and the ratio giving maximum efficiency in the ideal case, and also as strikingly presenting to the mind how far we are still, in actual practice, from even an approximation to the ideal condition exhibited in the perfect engine.

TABLE II.

Ratios of Expansion giving Maximum Work at Minimum Cost for a Given Plant of Known Proportions.

	Class I.						Class II.					
Cases	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
N	.04	.04	.04	.04	.04	.04	.10	.10	.10	.10	.10	.10
r_e^{iv}	$1\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{3}{4}$	$3\frac{1}{4}$	$3\frac{1}{2}$	4	$1\frac{3}{4}$	$2\frac{1}{2}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	4

	Class III.						Class IV.					
Cases	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.	XXIII.	XXIV.
N	.10	.10	.10	.10	.10	.10	.12	.12	.12	.12	.12	.12
r_e^{iv}	$2\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{1}{4}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{3}{4}$	4	$4\frac{1}{2}$	$4\frac{3}{4}$	5	5	$5\frac{1}{4}$

Table II gives values, similarly obtained for the cases taken, of that ratio of expansion which gives a maximum quantity of work for a dollar with a fixed proportion of plant. These values are seen to be very much smaller than the ratios for maximum commercial efficiency, and, although they may give more work for a dollar than the higher ratios just determined, they do not give maximum efficiency of capital. For :

Assume the engine working at this newly adjusted ratio for the now given power, still more work will be given for the dollar if the value of r be increased by replacing the given engine by a larger one, in many cases, or in any case by speeding up the engine or otherwise doing the larger amount of work with the higher ratio of expansion. The writer has sometimes accom-

plished this latter result by both speeding up the engine and carrying higher steam,* with an automatic adjustment of expansion. The real limit to this increase of work done by the given engine is determined by quite other considerations than those above noted. It is determined by the money value of the power obtained, and this increase of power finds a limit, as has been seen, only when either the limit of safety in working engine or boiler is reached, or when the money made by the use of additional power is insufficient to pay a fair profit on the additional expense incurred, which latter limit may be obtained at a value of r either equal to or less than r_c^{iv}.

15. *Relation of Costs and Profits.*

Table III exhibits the effect of variation of actual value of the power in determining the maximum amount profitably obtainable from any engine.

For example: Suppose the cost of a horse-power to be, as is frequently the case, about equal to the cost of fuel (in the furnace) producing that power without expansion; then calling this value P_m and this cost P_c, the base line of the diagram will be extended until it measures $\left(\frac{P_m}{P_c} = 1 = N^1\right)$ twice the length of OX, and the angle made by the line from its extremity to A, Fig. 2, makes an angle $\theta = 45°$ with OX. On the large-scale drawing, set the triangle against the edge of the T-square, and adjust it to the line here given; find, by shifting it along the blade, that point on the selected curve of efficiency at which a parallel tangent can be drawn, and then the ratio of expansion, r^{v} answering to this case, is found.

If an engine, IV of Class I, is selected, it is found to be $r^{\text{v}} = 2\frac{1}{2}$; if No. VII of Class II, $r^{\text{v}} = 2$, etc., etc., as in Table III.

It is particularly interesting and instructive to observe how the importance of cylinder condensation, in its influence on the best ratio of expansion, diminishes with increasing expansion, and that, finally, the most economical and the least efficient give nearly identical figures when the point of cut-off approaches half stroke.

* A favorite occupation of the writer, when engaged in this branch of professional work, was that of designing new and larger steam cylinders for old engines, to meet this case.

Table III.

Effect of Variation of Ratio to Market Value to Cost of Power. Maximum Limiting Values of r^r.

			N^1	0.40	0.50	0.60	0.70	0.80	1.00
Class		No.	IV	...	...	...	...	3	$2\frac{1}{2}$
"	II	"	VII	...	...	...	...	...	2
"	II	"	X	...	...	...	...	...	2
"	III	"	XV	...	7	5	4	3	$2\frac{1}{2}$
"	III	"	XVII	...	7	5	4	3	$2\frac{1}{2}$
"	IV	"	XXI	9	7	6	4	3	$2\frac{1}{2}$
"	IV	"	XXIV	10	7	6	4	3	$2\frac{1}{2}$
θ				22°	27°	31°	35°	39°	45°

Taking the cost of fuel, *in the furnace*, for the engine working without expansion, at $50 per annum per horse-power, the above table gives the ratio of expansion below which a loss will accrue when the cash value of the horse-power is 20, 25, 30, 35, 40 and 50 dollars; at these ratios of expansion, all that is received for power above these sums is profit.

For other costs, the prices obtained must be correspondingly varied to secure a profit.

16. *Profits at any Fixed Expansion.*

Other problems, the converse of the last, may be solved by this construction: "What is the maximum price which can be paid for power without loss at any *given best ratio of expansion?*" "What profit is obtainable at lower cost?" "What total cost makes any given ratio the most economical ratio of expansion?"

To solve these problems, draw an ordinate to the line of mean pressures, or the curve of efficiency, at the assumed ratio of expansion; the abscissa measures the cost in terms of full steam of the power measured by the ordinate, above which loss will accrue, when $M = 0$. The difference between the total cost and the market value measures the profit obtainable if the power is sold at the higher price of the two figures.

Table IV exhibits the variation of the relative maximum allowable cost of power, with variation of the ratio of expansion, actual cost of expenses, variable with fuel without expansion, being taken as unity.

TABLE IV.

Maximum Limit of Relative Allowable Cost. Most Economical Ratio of Expansion assumed as r. Cost of Full Steam, Unity. M or $N = 0.1$.

			r	1	2	3	4	5	6	8	10
Class	I	No.	IV	1.1	.80	.75	.75	.85	.85	...	...
"	II	"	VII	1.1	.80	.85	1.1	...	...	...	...
"	II	"	X	1.1	.75	.80	.95	...	...	...	...
"	III	"	XV	1.1	.75	.70	.70	.75	.80	.90	1.1
"	III	"	XVII	1.1	.75	.70	.70	.70	.70	.75	.90
"	IV	"	XXI	1.1	.75	.70	.90	.65	.70	.75	.90
"	IV	"	XXIV	1.1	.75	.70	.65	.65	.55	.55	.65

17. *Cost of Engine as Affecting the Best Ratio of Expansion.*

The effect of variation in cost of engine now becomes of interest, and indeed a matter of real importance to the designer. Studying cases arising in practice, he will probably find the value of M or N to fall between .02 and .15, as in those selected above, but it will probably rarely, if ever, exceed 0.20.

The curve being established correctly for any given engine, it becomes the easiest possible matter to determine the effect of variation of this ratio. Table IV (A) gives such results as seem most instructive, from the cases here studied.

TABLE IV (A).

Effect of Variation of "Engine-cost Ratio." Best Values of r_o^{iii} or r_o^{iv}.

			M or N	.02	.04	.06	.08	.10	.15	.20
Class	I	Example	IV	$3\frac{1}{2}$	$3\frac{1}{4}$	3	$2\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{1}{4}$
"	II	"	VII	...	2	2	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{2}{3}$	$1\frac{1}{2}$
"	II	"	X	...	4	$3\frac{3}{4}$	$3\frac{1}{2}$	$3\frac{1}{4}$	$2\frac{3}{4}$	$2\frac{1}{2}$
"	III	"	XV	...	6	5	$4\frac{1}{4}$	4	$3\frac{1}{2}$	3
"	III	"	XVII	...	8	6	$4\frac{3}{4}$	$4\frac{1}{2}$	$3\frac{3}{4}$	$3\frac{1}{4}$
"	IV	"	XXI	...	$6\frac{1}{2}$	6	$5\frac{1}{2}$	$4\frac{3}{4}$	$3\frac{3}{4}$	$3\frac{1}{4}$
"	IV	"	XXIV	...	9	7	6	5	4	$3\frac{1}{2}$

These differences in the value of the ratio of expansion at maximum commercial efficiency are least where the exhaust wastes are greatest, and as their absolute values become smaller. Cases IV, X, XVII, XXIV have the same initial steam-pressure, and are seen to approximate toward the same value of r_o as the

value of M or N becomes greater, becoming, for the first two, and for the last two, nearly equal to the maximum value here taken.

It is obvious that the value r_e becomes a good gauge of the economical value of the engine, and that the greater these values and the nearer r_e^{II}, r_e^{III}, r_e^{IV} approach each other, in any given engine, the better the design.

It is now seen that we have here a method of determining the effect of variations of single variable quantities, while retaining all others constant—a method very greatly needed, but hitherto unknown.

The case just taken is an illustration of its application. The following is another instance of no less importance.

18. *Back Pressure as Modifying Economy.*

The Effect of Variation in Back Pressure may be studied, by means of this method of investigation, with the same facility.

Table V exhibits this effect for a wide range of cases.

TABLE V.

Effect of Variation of Initial Pressure and of Back Pressure. Best Values of r_e^1.

			$\frac{p_b}{p_1}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{5}$	$\frac{1}{6}$	$\frac{1}{8}$	$\frac{1}{10}$	$\frac{1}{15}$	$\frac{1}{20}$
Class	I	No.	IV	$2\frac{3}{4}$	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{1}{2}$	...	...	...	...
"	II	"	VII	$1\frac{1}{2}$	$1\frac{3}{5}$	$1\frac{2}{3}$	$1\frac{3}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$	...	...
"	II	"	X	...	...	...	$1\frac{3}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$	3	4
"	III	"	XVI	...	...	...	$4\frac{1}{2}$	6	7	9	11
"	IV	"	XXII	...	...	...	6	6	8	12	15

These differences in value of r_e are obtained on the assumption that cylinder condensation and all other conditions remain unchanged while variation occurs in the back pressure. In all actual cases, the differences would be reduced by the fact that increased condenser-pressure and the reduction of chilling effect which comes with increase of back pressure so check exhaust waste that the ratio for maximum efficiency becomes somewhat increased, and these differences of ratio are thus lessened. The gain from this and other causes becomes sufficient at high pressures to justify the use of the simpler and less expensive non-condensing engine; it will be best appreciated after comparison of Class I with Class II.

19. *Illustrations of the Value of Results.*

In illustration of the use of this method and of the application of the results, we may observe, as in Table I, values of the ratio of expansion for maximum efficiency for any standard type of engine. Thus: Case III is that of an ordinary, standard, non-condensing, drop cut-off engine, steam 65 pounds ($5\frac{1}{3}$ atmospheres) by gauge, and the cut-off occurs, properly, at a little inside $\frac{1}{4}$ stroke; Case V is the same with steam at 105 by gauge (8 atmospheres) and its valve should close at a little inside $\frac{1}{6}$ stroke.

For maximum *commercial* efficiency those engines should "cut off" at about $\frac{1}{3}$ and $\frac{1}{4}$ respectively.

In the second class, Case VII is that of the old naval or modern very low-pressure river-boat engine carrying 25 pounds of steam by gauge ($2\frac{2}{3}$ atmospheres). The valve should drop so as to completely shut off steam at about half stroke to give minimum expenditure for coal, and a little later to give minimum cost on total account,* a result already reached by the builders of such engines.

Case VIII is that of some of our Hudson River steamboats (steam 45 by gauge), and these two ratios are found to be a little greater and a little less than 3. The irregularity of wheel which a short cut-off produces, however, makes it inadvisable to expand as much as this, even.

Case IX is often seen in mill engines; its valve closes at $\frac{1}{4}$ and $\frac{1}{3}$ for the cases taken. Above this pressure, a comparison of Class I with Class II shows that in the cases taken the non-condensing engine is about as economical as the other—a conclusion justified by Isherwood's comparison of Corliss engines †—but comparing values of r_e^{II} it is seen that the condenser may probably be exchanged for the heater with Classes III and IV only at some very high pressure not yet attained with jacketed engines of good design, while the ten per cent. gain obtained at the boiler by the higher temperature of feed given by the heater of the non-condensing engine, together with the differences in

* Engines of this class by good builders, having the "Stevens valve gear," close the valve at 6 feet on a 10-feet stroke, which, allowing for a little throttling, gives exactly this figure. Those fitted with the "Sickles cut-off," drop the valve as near half-stroke as possible; they cannot "follow" further.

† Journal Franklin Institute, September, 1881.

size of cylinder, brings down the pressure at which total efficiency becomes a minimum to some lower figure, which may be determined, by the method here given, for any given case.

Cases XV and XVI are commonly illustrated on transatlantic steamers and by the best compound pumping engines. The cut-off takes effect at $\frac{1}{8}$ or $\frac{1}{9}$ for maximum efficiency of engine and fuel, and at $\frac{1}{6}$ or $\frac{1}{7}$ for most economical expenditure of money,* figures already settled upon by the most successful builders.

Cases XII and XIII represent the most advanced practice in the use of high steam pressure, superheated steam, and reheating at the intermediate receiver, as is done in the pumping engines of Cowper, Corliss, and Leavitt. The best ratios of expansion are 12 and 15, if measured by duty attained and fuel saved, simply, and two-thirds those values give maximum efficiency of capital. Case XXIV represents most nearly the case of Corliss's best pumping engine, which lies between XXIII and XXIV; its best ratio of expansion lies between 9 and 10, if the Curve of Efficiency here taken for Class IV suits that case. If nine is the *real* ratio, the *apparent* cut-off will be nearly at one-tenth; while, for maximum efficiency of engine and maximum "duty," the valve should drop at about one-sixteenth stroke.

It should be carefully kept in mind that the measure of cost, in all problems relating to expense, as here treated, is the total cost per annum, without expansion, of all items of Class III, *i. e.*, variable with variation of steam supply.

The problem illustrated by the cases taken up in Table II would seem to be of rare occurrence. In fact, the writer has been able to imagine but two such cases:

(1.) Where the proprietor of an engine can rent power from an engine already set up with boiler power sufficient to supply an ample amount of steam, he will obtain the best return from his invested capital by delivering so much power at remunerative prices as will give the values r_e^{iv}, found in Table II. Cases IV, V, and VI are such as are most usual, the best point of cut-off averaging about $\frac{1}{3}$ stroke.

Had the power to be demanded been known, the proprietor would have done better to have put in a larger or a faster-running engine with a higher ratio of expansion, and would usually find it economical to alter the engine here assumed to

* *Vide* "Clark's Manual for Mechanical Engineers," pp. 888, 890.

be used—in the manner already described—if possible, so as to deliver the maximum power, working at the shorter cut-off.

(2.) The second is that of a naval engine intended to work with maximum efficiency at low power or long runs, and only requiring high power for short periods of time. It has sometimes been customary to design such engines to work with high ratios of expansion while cruising, and to develop full power with less expansion when in action, supplying a fan blast for the latter occasion. For such cases the best ratio at low power would be r_e^{II}, and it might be well to make the expansion variable through as wide a range as from r_e^{II} to r_e^{IV}, taken with extreme values of M and N. As already stated, in all ordinary work, the Ratio of Expansion at Maximum Commercial Efficiency is the ratio of expansion to be adopted for any engine.

The values here given for M and N are based on cost of fuel taken at \$5.00 per ton. The value of the ratios of expansion at maximum efficiency will be less at lower prices and greater at higher costs, the expenses of maintenance of plant being constant, since the values of cost of steam will be directly and of M inversely as the price of fuel. With coal at ten dollars per ton, M will be practically one-half the figures given above and the least ratio of expansion correspondingly increased as per Table V.

Table III may be consulted by the owner of steam-power for cases which, as is usual, fall within the given limits. For exceptional cases he, or his consulting engineer, can, when data are obtainable, always make his own curve of efficiency and obtain a practically exact solution of the case presented.

20. *Variation of Cylinder Condensation with Expansion.*

One other among the numerous problems capable of solution by this most prolific of methods promises, in the opinion of the writer, to prove, in the future, both interesting and important:

"*Given:* The method of variation of efficiency with varying ratios of expansion or proportions of steam used, to determine the method of cylinder condensation with varying values of $\frac{1}{r}$."

To solve this problem, construct the Curve of Efficiency, as A, D, E, O, Fig. 37, and draw the curves of adiabatic mean pressures for various values of x, as in dotted lines in that figure.

The points of intersection of these curves with the curve of

efficiency identify the ratios of expansion at which the total condensation amounts to the proportion due to the adiabatic line so cut.

In all problems of maxima or minima solved by the construction here given it will be observed that the item of quantity of expenditure made the independent variable is that dependent upon the quantity of steam or of fuel demanded by the engine.

21. *Problems solved by the Inspection of the Diagrams.*

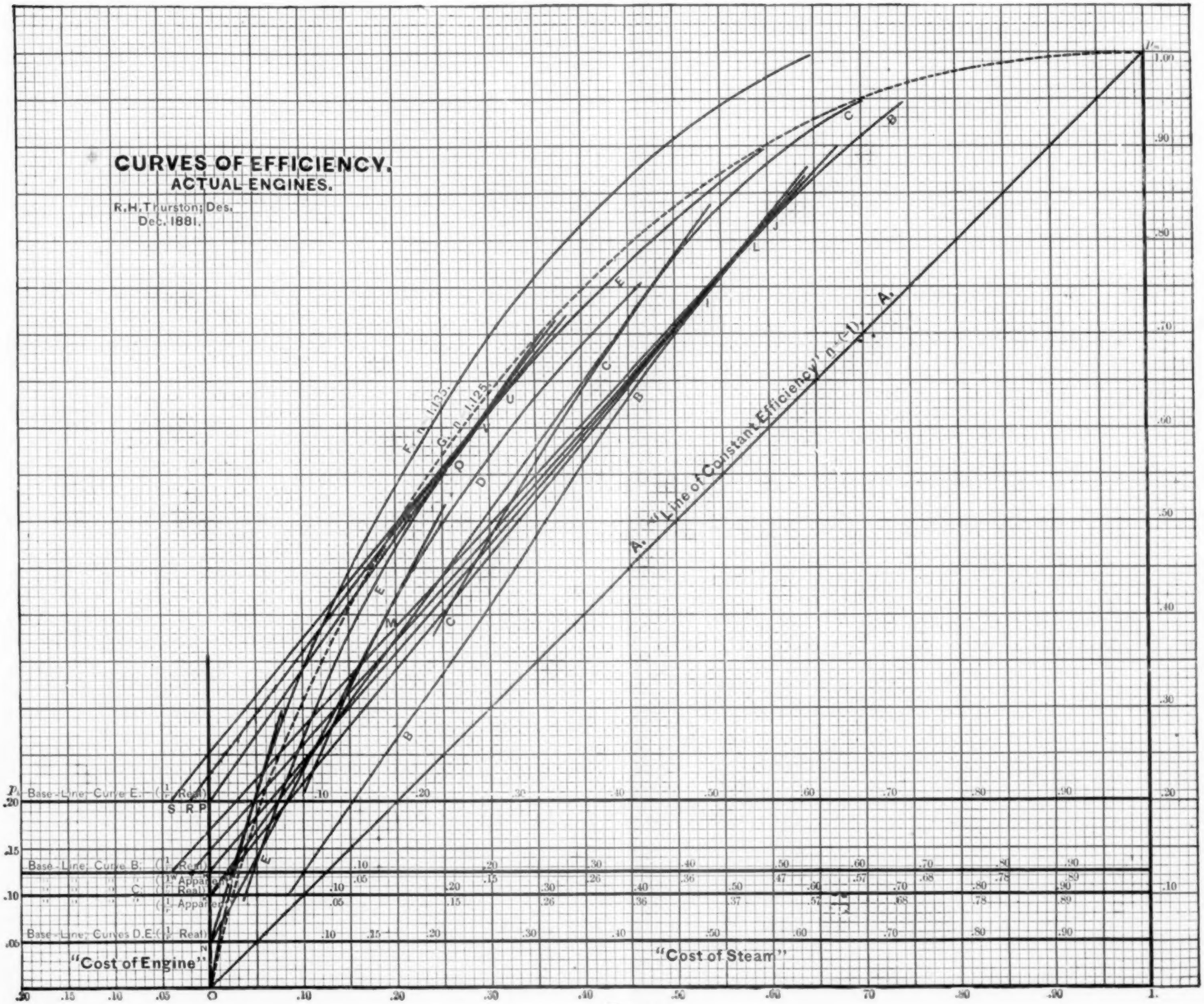
An important class of problems of simple character may be solved with still greater ease and rapidity by the use of the Curve of Efficiency for the class of engine studied in any case, *e. g.:*

(1.) To determine the gain or decrease of power obtainable by change of ratio of expansion or point of cut-off, measure the ordinates of the curve at the present and at the proposed ratio of expansion; their relative magnitude will be a measure of the relative power of the engine at the two points of cut-off, if using the quantity of steam measured by the abscissas.

(2.) To determine the quantity of fuel or of steam, per hour per horse-power, to be gained or lost by change of the ratio of expansion, compare the value of ratios of abscissa to ordinate at the existing and proposed points of cut-off; their relation will be that of cost of power in steam or in fuel.

(3.) To determine the absolute amount of fuel or of steam per horse-power and per hour consumed, at any assumed rates of expansion, first calculate the consumption for the given engine as a thermodynamic problem simply, and multiply by the ratio, $\frac{y}{p_m}$, of the mean pressure in the perfect engine at the given expansion to that shown by the true Curve of Efficiency for the engine studied. Or, calculate the consumption for the engine working without expansion and without waste, and multiply by the ratio, $\frac{p_1}{p_m y}$, obtaining y and p_m from the diagram N, the given cut-off, and remembering that p_1 measures the mean pressure at full stroke of the given steam used *dry*.

It is evident that when costs of engine can be referred, as here taken, to the same unit of volume, the solution of the problem of maximum commercial efficiency is independent of size of



CURVES OF EFFICIENCY.
ACTUAL ENGINES.
R.H. Thurston; Des.
Dec. 1881.
"Line of Constant Efficiency"
"Cost of Engine"
"Cost of Steam"
Base-Line, Curve E.
Base-Line, Curve B.
Base-Line, Curves D.E.

FIG. 38.

engine and of the absolute measure of power demanded, and hence applies to all engines of the same pattern.

22. *Conclusions.*

In view of what has preceded, it becomes obvious that the engineer proposing to write a specification for steam machinery on which bids are to be made with guarantee of performance should *first* determine the probable *Curve of Efficiency* for the kind of engine called for and solve the above problems relating to its economy. He should then prescribe the ratio of expansion at which maximum duty is to be obtained, as well as fix the duty expected in regular work, at which ratio the work done will be less than the regular working power of the machine. He must also indicate at what degree of expansion the engine will be required to do its ordinary work at maximum *commercial* efficiency, and should state what minimum commercial economy at that rate of work will be accepted. Finally, it should be prescribed that the engine should be capable, if its work should be increased, of attaining at least its "maximum efficiency of plant" with safety at maximum pressure, and with a specified efficiency, which should be reasonably high.

Thus fixing the ratio of expansion on the duty-trial, the builder is able to give an intelligently estimated guarantee of performance at highest efficiency; settling the ratio of expansion for maximum commercial efficiency in regular work fixes the proper size of engine, and the last specification secures ample strength of parts. Costs must be carefully estimated for the given locality. In what has preceded, the calculations have been based on cost of fuel estimated at $5.00 per ton, and labor at $2.00 to $3.00 per day, and interest at 6 per cent.

In laying out the curve of efficiency from experimental data it will be found necessary to be especially careful to establish the usually irregular scale of $\frac{1}{r}$, the points of cut-off, in their correct relation to the regular scale of steam expenditure and "cost of steam."

By the use of this, or some more exact method, the art of proportioning the steam-engine can be elevated to the rank of a branch of the Science of Engineering, and that part of that science which has hitherto been in a most unsatisfactory state, as viewed from the standpoint of the engineer engaged in its

application, may be found to take a comparatively complete and useful form.

The subject is here presented only provisionally. The effects of varying compression and of conditions relating to regulation, as well as many other minor conditions, remain to be studied. In a first survey of so broad a field, and especially where the needed data are so difficult to obtain and so uncertain as to accuracy, the writer cannot hope to have completely and exactly established all the results sought by him, and a revision of this work in the light of further investigation will probably ultimately lead to more correct and more valuable determinations.

It is even to be hoped, if not expected, that an exact theory of steam-engine economy may, at some early date, be produced, and that thus the engineer may be enabled to obtain solutions of such problems with all the precision that can ever be desired.

Added since the Meeting.

Note.—In this paper, the cost of engine is reckoned per cubic foot of cylinder. It is customary to reckon the value of large engines by the pound, and their weight by the cubic foot of cylinder. Weights per cubic foot of steam-cylinder are given in Haswell's *Pocket Book* (41st ed., pp. 605 *et seq.*) for various types.

In a paper by Professor Trowbridge,* which has come to the notice of the writer since the above paper was written, are given weights and prices of stationary engines. The latter become nearly constant when reckoned per cubic foot of cylinder, for sizes exceeding about 50 H. P.,—a fact of the more value since the figures are presented to sustain an opposite conclusion.

Where the costs do not so vary, this method is applicable by a system of approximation, assuming the probable cost of engine and repeating the work, using a corrected cost based on the first result.

* Jour. Franklin Inst., July, 1882.

LXXV.

REPORT OF A TRIAL OF UPRIGHT BOILERS AND WORTHINGTON COMPOUND PUMPING ENGINE,

AT THE

ROXBURY PUMPING STATION, BOSTON, MASS.

JULY, 1879.

BY

J. S. COON, CAMBRIDGEPORT, MASS.

DESCRIPTION OF PLANT.

THE steam-generating apparatus employed during this trial consisted of two upright cylindrical tubular boilers, with internal furnaces, the boilers being located in brick setting. The product of combustion, after passing out of the top of either boiler, was conducted downward externally to the shell of the boiler, and in contact with the same, through flues in the brick setting. By referring to a sketch of the boilers it will be seen that considerable surface was available for superheating.

The principal dimensions of the boilers are as follows:

Diameter of circular shell,	84 inches.
Height, over all, about,	14 feet.
Diameter of circular grate,	69 inches.
Distance from grate to lower tube sheet,	2 ft. 5½ inches.
Number of wrought-iron tubes in each boiler,	220.
Length of each tube,	10 feet.
Internal diameter of each tube,	2¼ inches.
External " " "	2½ "
Water space about fire-box,	7 "
Grate surface in each boiler,	25.96 sq. feet.
" " " both boilers,	51.92 " "

Surface exposed to furnace gases in each boiler:

In fire-box,	64.3 sq. feet.
Internal surface in tubes,	1295.6 " "
Fire surface at top of boiler,	33.8 " "
" " external to shell of boiler,	112. " "
Total fire surface in one boiler,	1506. " "
" " " " both boilers,	3012. " "
Ratio of fire surface to grate surface,	58 : 1.
" " grate surface to internal cross-section of tubes,	4.27 : 1.

THE PUMPING ENGINE.

The pumping engine, whose duty was incidentally obtained at this trial, was a Worthington compound engine, of the ordinary type, having horizontal, direct-acting steam cylinders and pumps, there being two plungers, each driven by one high-pressure and one low-pressure cylinder.

The principal dimensions of the engines are as follows:

Diameter of high-pressure pistons, each,	21 inches.
" " low " " "	36 "
" " high-pressure piston-rods,	3 "
" " low " " "	$2\frac{1}{4}$ "
(There were two piston-rods to each low-pressure piston.)	
Diameter of pump plungers, each,	17.5 inches.
" " " " rods,	3. "
Stroke of engine No. 1,	3.165 feet.
" " " No. 2,	3.17 "
Mean stroke of both engines,	3.1675 "

Throughout the trial both engines made their full length of stroke.

METHOD OF CONDUCTING THE TRIAL.

The method adopted in conducting the trial is due to Mr. Richard H. Buel, of New York, and was the same as that used by Mr. Buel when testing the Lawrence and Pawtucket pumping engines.

Before commencing the trial the steam pressure was brought, in the boilers, to the minimum point that would readily enable the engine to do its work. The fires were then hauled, and the furnaces and ash-pits cleaned. The fires were then rekindled with wood, the steam pressure and water level being noted when the fires were lighted. Coal was added at once, and when the fires were in sufficiently good condition the engine was started and continued running until, after the last firing, the steam pressure had fallen to the point at which it stood when the fires were started, the water level being also the same. The engine was then stopped, the fires hauled, and the unconsumed coal picked out. This latter was deducted from the total coal supplied to the boilers during the trial, the remainder being charged to the experiment. The wood used in starting fires was also charged to the experiment, it being estimated as equivalent to four-tenths of its weight in coal.

The coal used during the trial was selected "Old Company's" Lehigh, of the very best quality.

During the trial the feed-water was supplied to the boilers directly from the street main, and its mean temperature was 74.56° F. Ordinarily the feed-water enters the boilers at 130° F., but as suitable connections could not be made for gauging the water after it was heated, it was supplied at the temperature of the street main. During the ordinary daily work the feed-water is heated by the exhaust steam from the direct-acting boiler feed-pumps.

It was inconvenient to weigh each draught of feed-water. It was gauged in a barrel fitted with fixed hook gauges, and by these uniformly filled and discharged each time, each draught weighing 374 lbs., as previously ascertained. From the measuring barrel the water was run into another, to which the pump connection was attached.

A mercurial column indicated the pressure per square inch in the force main, *i. e.*, the forward pressure against which the engine pumped. The mean of the recorded observations made on this gauge indicated a pressure of 78.703 lbs. per square inch.

The water supply for the main pumps was drawn from a street main under pressure, which assisted the engine in pumping. A mercurial column was used to indicate this back pressure. The mean of the observations taken from it, indicated a pressure of 27.11 lbs. per square inch.

The zero of the force-main gauge was 4.64 feet above the zero of the back-pressure gauge,—being equivalent to about 2.008 lbs. per square inch additional pressure. The head against which the engine pumped was therefore $(78.703 + 2.008) - 27.11 = 53.6$ lbs.

The boiler pressure gauge had been previously tested.

Tubes partially filled with oil were inserted into the flues to determine the temperature of the products of combustion as they left the boilers. Thermometers immersed in the oil indicated the temperature.

A thermometer was inserted into the main steam-pipe, about 10 feet from either boiler, to indicate the temperature of the steam.

A thermometer was inserted into the feed-pipe, between the feed-pump and the boilers, for indicating the temperature of the feed-water. A thermometer was also immersed occasionally

in the measuring barrel, during the early part of the trial, to obtain the temperature of the feed-water. But as its indications agreed exactly with those of the thermometer in the feed-pipes its use was subsequently discontinued.

A mercurial column indicated the amount of vacuum obtained in the condenser. This gauge indicated 0.4 inches too much.

Throughout the trial observations were made every thirty minutes on the engine counter (which indicated every four strokes of the engine); the force-main pressure gauge; the back pressure gauge; the vacuum gauge; the steam pressure in boilers; the temperature of the steam in the steam-pipe; the temperature of the boiler flues; the temperature of the feed-water, and the temperature of the engine-room.

Indicator diagrams were frequently taken from all four steam cylinders throughout the trial. The cards show a very uniform pressure in the high-pressure cylinders, not only throughout each single stroke, but also throughout the entire trial.

One man was engaged whose sole duty was to measure the feed-water.

RESULTS OF THE TRIAL.

Fires were hauled and ash-pits cleaned at 4.50 A.M. Fires were lighted at 5.07 A.M., with boiler steam-gauge at 29.5 pounds.

One hundred and fifty pounds of wood were used in each boiler to start fires.

The engine started at 5.50 A.M., with boiler steam-gauge indicating 44.5 pounds.

Engine run continuously till 9.21 P.M., when it was stopped,—the boiler pressure having fallen to 29.5 pounds, and the water standing in the glass gauge at the same point as when the fires were lighted, viz., 5.07 A.M.

The fires were hauled immediately after the engine was stopped.

Duration of trial, from the time the fires were lighted, at 5.07 A.M., till they were hauled, at 9.21 P.M., was sixteen hours and fourteen minutes.

Time during which engine was run, viz., from 5.50 A.M. till 9.21 P.M., fifteen hours and thirty-one minutes.

The following table gives the mean and total quantities as recorded in the log:

Mean pressure in force main, pounds per sq. inch, .	78.703
Mean pressure in suction main, pounds per sq. inch, .	27.11
Difference, pounds per sq. inch, ...	51.593
Correction for difference in zero points, pounds, . .	2.008
Mean corrected head against pumps, pounds per sq. inch,	53.6
Mean corrected vacuum, pounds per sq. inch, . .	12.55
Mean steam pressure at boiler gauge, pounds per sq. inch,	38.985
Mean temperature of the feed-water, F., ...	74.561°
Mean temperature of the steam in main steam-pipe, F.,	352.5°
Mean temperature of the flue, boiler No. 1, F., . .	317.3°
Mean temperature of the flue, boiler No. 2, F., . .	316.9°
Mean temperature of the engine-room, F., ...	84°
Total indications of engine counter, ...	11312
Total number of pump strokes, ...	45248
Total pounds of water evaporated, ...	29876.5
Total pounds of wood used to start fires, ...	300
Total pounds of wood used, in coal equivalent, 40 per ct.,	120
Total pounds of coal put into furnaces, ...	3711
Total fuel, in coal equivalent, pounds, ...	3831
At the close of the trial there were drawn from the grates, pounds, ...	511
Ditto from ash-pits, pounds, ...	256
Total ashes and unburned coal from both grates and pits, pounds, ...	767
Total unburned coal picked out from the above, pounds,	519
Total coal consumed, 3831 − 519 pounds, ...	3312
Total ashes, 766 − 519 pounds, ...	248
Percentage of ash in coal	7.48
Total combustible consumed, 3831 − 767 pounds . .	3064

ACTUAL DUTY OF THE PUMPING ENGINE DURING THE TRIAL.

Total head against pump, net, per square inch, pounds,	53.6
Mean area of plungers, square inches, ...	236.994
Total indications of the counter, ...	11312
Feet travelled by the plungers at each indication of the counter, ...	12.67
Total coal consumed, pounds, ...	3312

Hence duty was (foot-pounds per 100 pounds of coal),

$$\frac{236.994 \times 53.6 \times 12.67 \times 11312. \times 100}{3312.} = 54,970,264.$$

TRUE DUTY WITH WHICH THE ENGINE SHOULD BE CREDITED.

As previously stated, the feed-water is ordinarily supplied to the boilers at a temperature of 130° F., instead of the temperature named during the trial, viz., 74.561°. Hence the actual duty, as previously given, is less than the duty which should fairly be credited to the engine.

The thermal units imparted to one pound of water at 74.56° in converting it to steam at 53.69 pounds absolute pressure (38.985 pounds gauge), and superheating it to a temperature of 352.5° = 1150.78 thermal units.

The thermal units which would be imparted to one pound of water at 130° in converting it to steam at same pressure, and superheating as given above, = 1095.17 thermal units.

Hence, in consequence of using the cooler feed-water, the consumption of coal was increased in the ratio of 1150.78 to 1095.17, or 5.078 per cent., bringing the duty of the engine up to 57,761,517 foot-pounds.

EFFICIENCY OF THE PUMP.

From a mean of several sets of indicator cards taken at wide intervals during the trial, the percentage of the pressure on the pump plungers was 90.775 per cent. of the pressure on the steam pistons,—the water pressure on the plungers being taken at the same time the cards were taken from the steam cylinders.

SUPERHEATING.

Mean observed steam pressure at boilers, by gauge, .	38.985 pounds.
Mean barometric pressure (29.938 inches mercury), .	14.705 "
Mean absolute pressure of evaporation, per sq. inch, .	53.69 "
Temperature of evaporation corresponding to this pressure, ...	285.7° F.
Mean observed temperature of steam in main steam-pipe, ...	352.5° F.
Degrees which steam was superheated, ...	66.8° F.
Thermal units imparted to each pound of steam in superheating (66.8 × .365), ...	24.38
Thermal units required to evaporate one pound of water from 74.56° F. to saturated steam at 53.59 pounds, =	1126.4
Increase due to superheating, ...	2.16 per cent.

HOURLY QUANTITIES.

Pounds of coal, ...	213.7
" combustible, ...	197.7
" coal per square foot of grate, ...	4.115
" combustible per square foot of grate, . . .	3.807
" coal per square foot of fire surface, . . .	0.0794
" combustible per square foot of fire surface, .	0.0656
" feed-water per square foot of fire surface, . .	0.64

EVAPORATION.

Pounds of water per pound of coal, at observed temperature and pressure, ...	9.027
Pounds of water that would have been evaporated per pound of coal at observed pressure, had feed-water been at 130° F.,	9.463
Pounds of water evaporated per pound combustible at observed temperature and pressure, ...	9.7508
Pounds of water evaporated per pound of combustible at observed pressure, had feed-water been supplied at 130° F., .	10.22
Pounds of water evaporated per pound of coal from and at 212° F., neglecting superheating, ...	10.515
(Factor of evaporation being 1.1648.)	
Pounds of water evaporated per pound of coal from and at 212° F., taking into account the superheating. . . .	10.742

The quantity 10.515 represents the actual evaporation from and at 212° F. The quantity 10.742 represents what the evaporation would have been if the steam had been sent to the engine dry saturated, and supposing the products of combustion to have been cooled to an equally low degree.

Pounds of water evaporated per pound combustible, from and at 212° F., neglecting superheating, ...	11.358
Pounds of water evaporated per pound combustible, from and at 212° F., taking account of the superheating, ...	11.603
Pounds of water evaporated per hour, per square foot of heating (fire) surface, neglecting superheating, ...	0.745
Pounds of water evaporated per hour, per square foot of heating (fire) surface, taking account of superheating, . . .	0.759

The factor of evaporation given above, viz., 1.1648, is based on the observed temperature of feed-water, viz., 74.561° F., and on the temperature of evaporation corresponding to the mean observed boiler pressure, viz., 38.985 pounds gauge. Taking into account the superheating, the factor of evaporation becomes 1.1864.

HORSE-POWER DEVELOPED.

Area of pump plungers, mean, square inches, ...	236.99
Head against pump, pounds per square inch, ...	53.6
Mean indications of counter per minute, ...	12.15
Feet travelled by plungers per each indication of counter, .	12.67

Hence, net horse-power $= \dfrac{236.99 \times 53.6 \times 12.15 \times 12.67}{33000} =$ .. 59.26

The efficiency of the engine being, as previously given, 0.9077,

the indicated horse-power $= \dfrac{59.26}{.9077} =$ 65.28

PERCENTAGE OF BOILER PRESSURE REALIZED IN HIGH-PRESSURE CYLINDERS.

The mean pressure above the atmosphere from all the high-pressure cards was, pounds per square inch, ...	15.5
Mean barometric pressure, ...	14.7
Mean absolute pressure realized in high-pressure cylinders, .	30.2
Mean absolute pressure of steam in boilers, ...	53.69
Percentage of boiler pressure realized in high-pressure cylinders,	56.2

THE RELATIVE AMOUNT OF WORK DONE BY THE HIGH-PRESSURE AND LOW-PRESSURE CYLINDERS, RESPECTIVELY.

The following quantities may represent the amount of work done at each end of each steam cylinder for each engine, as given by the indicator cards :

High-pressure cylinder, back end, right-hand engine, . .	6916.8
" " piston-rod end, right-hand engine, .	6609.4
" " total for both ends, right-hand engine, ...	13526.2
Low-pressure cylinder, back end, right-hand engine, . .	7573.0
" " piston-rod end, right-hand engine, .	6968.5
" " total for both ends, right-hand engine, ...	14541.5
High-pressure cylinder, back end, left-hand engine, . .	6961.8
" " piston-rod end, left-hand engine, .	6534.7
" " total for both ends, left-hand engine,	13496.5
Low-pressure cylinder, back end, left-hand engine, . .	7400.0
" " piston-rod end, left-hand engine, .	7271.5
" " total for both ends, left-hand engine,	14671.5
Total high-pressure work done by both engines, . . .	27022.7
Total low " " " " . . .	29213.
Percentage of work done by high-pressure cylinders, . .	48.05
" " " " low-pressure cylinders, . .	51.95

POUNDS OF COAL AND WATER USED PER HORSE-POWER PER HOUR.

Pounds of coal per hour per net horse-power at observed pressure and temperature of feed-water, ...	3.606
Pounds of coal per hour per net horse-power, at observed pressure, if feed-water had been supplied at 130° F., .	3.432
Pounds of coal per hour per indicated horse-power, at observed pressure and temperature of feed-water, . .	3.27
Pounds of coal per hour per indicated horse-power, at observed pressure, if feed-water had been supplied at 130 F.,	3.11
Pounds of feed-water per hour per net horse-power, .	32.53
Pounds of feed-water per hour per indicated horse-power,	29,52

STEAM ACCOUNTED FOR BY THE INDICATOR CARDS.

Assuming that the independent feed-pump took 1 per cent. of the feed-water supplied to the boilers, and assuming a clearance of 2 per cent. at the low-pressure cylinders, the indicator cards account for 87 per cent. of the feed-water supplied to the boilers.

It may be well to add that the object of this trial was to obtain additional data for deciding on the type of boiler to be used with the improved sewerage pumping engines, at Boston, and was authorized by Mr. Joseph P. Davis, then city engineer, Boston. The trial was conducted under the direction of Mr. E. D. Leavitt, Jr. The data taken from the Worthington engine were merely incidental. In order to avoid any imputation of unfairness, all observations were made jointly by myself and by Mr. Dexter Brackett and his assistants, from the City Hall, Boston.

Discussion.

Mr. Porter: It should be especially noted that the engine was not on trial. It was only the boiler that was on trial. The engine was a large engine performing very little duty. It was working under a boiler pressure of only fifteen pounds above the atmosphere, and, therefore, this performance, which was incidental, should not be recorded as any measure of the duty that the engine was capable of when it had a proper load, a load for which it was designed.

Mr. Nagle: These experiments having been instituted for the purpose of testing this boiler for its efficiency, with a view of its adoption for a sewage pumping-engine, it would seem that the test should have been made for a greater rate of consumption than that of which we have a record. These tests were made under the very exceptionally slow rate of combustion of less than four pounds of coal per square foot of grate, whereas the more common rate is ten to twelve pounds per square foot of grate. I desire to know if any tests were made that show the economy or efficiency at this more common rate of combustion?

Mr. Coon: No tests were made at a higher rate of combustion; but during these tests we used two boilers to supply the engine with steam, and when using only one, we found that the economy was not so good.

Mr. Nagle: Evidently when only one boiler was used for the engine, the rate of combustion must have been double that recorded, or about eight pounds per square foot of grate.

Mr. Coon: The economy is found not to be so good when one boiler is used as when two are used.

Mr. Nagle: But what the economy is when using only one boiler, when the rate of combustion is eight pounds per square foot of grate, we are not informed of.

Mr. Coon: No, sir.

Mr. Le Van: What is the difference between the flue temperature and the steam temperature?

Mr. Coon: The flue temperature was lower than that of the steam.

Mr. Le Van: I have found, where the flues exceeded thirty diameters in length, that anything exceeding that would tend materially to lessen the economy of the boiler. Had those experiments been made with a single boiler, the results as regards the consumption of fuel to work done would have been greater. Mr. President, Mr. Nystrom is present, and not being a member, I would ask the privilege be granted him of making a few remarks.

Mr. President: If there is no objection, Mr. Nystrom may take part in the debate.

Mr. Nystrom: I came in at the end of the paper. There was 87 per cent. of water accounted for. I would ask what volume of steam is used?

Mr. Coon: Those volumes were taken from the tables in the work of Mr. Porter, and they were taken from that wholly because that is the most readily available table, so far as I am aware.

Professor Robinson: It strikes me that attention should be called to this apparently low duty,—fifty-four million foot-pounds. The circumstances in this case are all unfavorable for high duty. I think that point should not be overlooked. It is in favor of the pump that it should be as high as that under the circumstances.

LXXVI.

NOTE ON THE ECONOMY OF THE WINDMILL AS A PRIME-MOVER.

BY

ALFRED R. WOLFF, M.E., NEW YORK CITY.

In the course of professional work I have repeatedly had occasion to investigate the question of the impulse of wind upon windmills, and to observe the economical performance of the latter. From time to time I have published various results of these investigations, but have not given a record of the actual economy of the windmill, the subject proper of this note. Before however, setting forth the special economy in the use of the windmill as a prime-mover for small powers, it is well to refer briefly to some publications which may be of interest in connection with the general subject.

For the early history of windmills, and a description of European windmills, Fairbairn's *Mills and Millwork* may be consulted to advantage. For a description of the details of American windmills, see article on Windmills in Appleton's *Cyclopædia of Mechanics*, 1880. For an account of experiments on windmills see Smeaton's *Miscellaneous Papers*, and Coulomb's *Théorie des Machines Simples*. For the best angles of impulse and "weather," for windmill blades, see *Engineering and Mining Journal*, October 7th, 1876, and Appendix I of this note. The question of the impulse of wind upon windmill blades involves, too, the consideration of the relation between the velocity and pressure of the wind. A concise summary of this question, useful to no small extent in its reference to the journals containing the original publications of those who have given the subject attention, will be found in a paper by Mr. F. Collingwood, C.E., read before the American Society of Civil Engineers, April 6th, 1881, on *An Examination into the Method of Determining Wind Pressures.* In Appendix II of this note will be found the tabulated result of the writer's own work in this connection, in which the effect of temperature has received its due consideration. In the *Journal of the Scottish Meteorological Society*, 1880, Mr. F. Stevenson describes some interesting experiments tending to show the effect

of the height of observation above the ground on the relative velocity and pressure of wind. (See also *Engineering*, January 14th, 1881.)

Having thus indicated some of the publications where can be studied those considerations which affect the construction of windmills, and which to some extent determine as well their efficiency, I propose now to direct attention to the demonstration of the fact that whatever improvement in efficiency be possible in the future, windmills, as at present constructed, are the most economical prime-movers for those uses for which they are specifically designed.

In this demonstration, conclusions will be based only on observed facts or actual running results. I am enabled to do this inasmuch as some five years ago one of the most prominent windmill manufacturers came to me with a few scattered data of actual performances of his mills, which, however, were sufficient by means of deductions and analogy from theoretical principles, to warrant the preparation of the following:

Designation of mill.	Velocity of wind in miles per hour.	Revolutions of wheel.	Gallons of water raised per minute to an elevation of						Equivalent actual useful horse power developed.	Average number of hours per day during which this result will be obtained.
			25 feet.	50 feet.	75 feet.	100 feet.	150 feet.	200 feet.		
8½ ft. wheel.	15 to 20	70 to 75	6.162	3.016	....	....	....	....	.04	8 to 10
10 ft. wheel.	15 to 20	60 to 65	19.179	9.563	6.638	4.750	....	....	.12	8 to 10
12 ft. wheel.	15 to 20	55 to 60	33.941	17.952	11.851	8.485	5.680	....	.21	8 to 10
14 ft. wheel.	15 to 20	50 to 55	45.139	22.569	15.304	11.246	7.807	4.998	.28	8 to 10
16 ft. wheel.	15 to 20	45 to 50	64.600	31.654	19.542	16.150	9.771	8.075	.41	8 to 10
18 ft. wheel.	15 to 20	40 to 45	97.682	52.165	32.513	24.421	17.485	12.211	.61	8 to 10
20 ft. wheel.	15 to 20	35 to 40	124.950	63.750	40.800	31.248	19.284	15.938	.78	8 to 10
25 ft. wheel.	15 to 20	30 to 35	212.381	106.964	71.604	49.725	37.349	26.741	1.34	8 to 10

Since the preparation of this table, over a thousand windmills have been sold on its guarantee, and in all cases the actual results obtained, both in this country and elsewhere, did not vary sufficiently from those above presented to cause any complaint whatever; a proof that the results, as tabulated, are very close, or certainly not too high. If it be claimed that the horse-power developed appears small, from the standpoint of a (false) prevalent popular opinion, it should be observed in response that the actual results noted in the table are in close agreement with those obtained by theoretical analysis of the impulse of wind upon windmill blades. The manufacturer's own observations,

during the past five years, have led him to conclude that they are correct. It will, therefore, be just to base the economy of the windmill as prime-mover on the performances recorded in this table, and the expense of obtaining the power will be presented further on.

Conceding for a moment its economy, the possible employment of the windmill as prime-mover is dependent as well on other considerations. The objection urged against the use of windmills is the uncertainty of the motive fluid—wind ; but we will see that this objection serves not to prevent, but only to restrict, the use of the windmill as prime-mover. Of course, it must be acknowledged that there are minutes and hours of total calm, and this restricts the employment of the windmill to such purposes, where either the nature of the work done by the wind mill allows of its being suspended during a calm, as work on a farm, for instance, or where the work can be stored, as in pumping water for a variety of purposes, or in compressing air, or, as was lately proposed by Sir William Thomson,* for storing electricity by means of dynamo machines and electrical accumulators. There is another restriction which goes into practical effect, namely, that the large size of a windmill for a given power makes it practically desirable only to be used for small powers, but actually it is only designed for the use of small powers, usually between $\frac{1}{25}$ and 4 horse-power ; † and for such powers it will be shown in this note that it is the most economical and serviceable prime-mover for the purposes for which it is designed.

The difficulty urged by Sir William Thomson against its adoption, in its present state of development, for storing electrical accumulators, is the *first cost* of the windmill, but this was doubtless an oversight,‡ for the *interest* on the capital expended, and

* Presidential address "On the Sources of Energy in Nature available to Man for the Production of Mechanical Effect," delivered before Section A of the British Association for the Advancement of Science, 1881.

† Coulomb, in his experiments with a windmill of four sails, 70 feet in diameter, breadth of sails, $6\frac{1}{2}$ feet, the wind blowing at a velocity of fifteen miles per hour, obtained an actual useful result equivalent to about 7 horse-power.

‡ In the same paper Sir William Thomson, in estimating the cost of utilizing the power of Niagara Falls for electric lighting, correctly considers the interest on first cost in determining the economical aspect of the question. The oversight, noted in the text, becomes important and worthy of mention only inasmuch as any statement of so distinguished and justly-esteemed an authority

not capital itself, becomes one of the items of current expense in judging of the economy of prime-movers, and, as will become evident from the contents of this note, the question of expense of producing power will not prove an objection, but, on the contrary, the best reason for the introduction of windmills to charge electrical accumulators.

It must be specially mentioned that experience has shown that the wind blows fast enough to run the windmill up to the regulating speed in the above table on an average of eight to ten hours per day of twenty-four hours, and our estimate of work done and expense of power will be based on an actual running of only eight hours per day.

The current expense of any prime-mover, or the cost of obtaining the horse-power developed per unit of time, which alone should form the basis of a comparison of the economy of different prime-movers, consists principally of interest, repairs, and depreciation of plant, cost of fuel, oil, and attendance. In windmills the cost of fuel is zero, wind being a free gift of nature. The attendance required for the self-regulating windmill, designated in the above table, amounts only to filling the oil-cups three or four times a month, the work of a few minutes, which any one can attend to. If any account is to be taken of this service, an allowance of fifteen cents a month would really be quite extravagant. In the following table such allowance has been made. Experience has shown that the repairs and depreciation items, jointly, are amply covered by 5 per cent. of the first cost, per annum. Interest is calculated at 5 per cent. per annum. The oil used is a very small quantity—a few gallons per year—and is allowed for in the table according to the size of mill. All the items of expense, including both the interest and repairs, are reduced to the hour by dividing the costs per annum by $365 \times 8 = 2920$, the interest, etc., for the twenty-four hours being charged on the eight hours of actual work. By multiplying the figures in column 5 by $\frac{365 \times 8}{100 \times .05} = 584$, the first cost of the windmill in dollars is obtained.

as Sir William Thomson, is apt to be accepted on the basis of authority alone; and it must be added that the great caution usually displayed by the most eminent living English physicist entitles him *prima facie* to this mark of consideration.

TABLE SHOWING ECONOMY OF THE WINDMILL.

1	2	3	4	5	6	7	8	9	10
Designation of mill.	Gallons of water raised 25 feet per hour.	Average number of hours per day during which this quantity will be raised.	Equivalent actual useful horse-power developed.	Expense of actual useful power developed, in cents per hour.					Expense per horse-power, in cents per hour.
				For interest on first cost. (First cost, including cost of windmill, pump, and tower. 5 per cent. per annum.)	For repairs and depreciation. (5 per cent. of first cost, per annum.)	For attendance.	For oil.	Total.	
8½ ft. wheel.	370	8	.04	0.25	0.25	0.06	0.04	0.60	15.0
10 ft. wheel.	1,151	8	.12	0.30	0.30	0.06	0.04	0.70	5.8
12 ft. wheel.	2,036	8	.21	0.36	0.36	0.06	0.04	0.82	3.9
14 ft. wheel.	2,708	8	.28	0.75	0.75	0.06	0.07	1.63	5.8
16 ft. wheel.	3,876	8	.41	1.15	1.15	0.06	0.07	2.43	5.9
18 ft. wheel.	5,861	8	.61	1.35	1.35	0.06	0.07	2.83	4.6
20 ft. wheel.	7,497	8	.79	1.70	1.70	0.06	0.10	3.56	4.5
25 ft. wheel.	12,743	8	1.34	2.05	2.05	0.06	0.10	4.26	3.2

The number of gallons pumped by the 30-foot and 35-foot mills and larger sizes and the economy of the same are not given in the above table, for the number of larger mills in operation is not sufficient to insure the authenticity of the results thus far obtained. The performance of the 30-foot mill, as far as observed, seems to gravitate to a pumping capacity equivalent to 2.4 horse-power, and an expense of 2.5 cents per horse-power per hour.

When the figures in the table are contrasted with the cost of pumping the same amount of water by other prime-movers, where in addition to expense of interest, repairs, depreciation, and oil, there are the greater expenses of fuel and attendance, and often extra insurance on property, owing to the use of steam, the economy of the windmill must be evident to all.

To recapitulate: The figures given in the body of this note are the results of actual experience with hundreds of windmills, and as such, it was believed, would not be without interest. They prove conclusively that at the present time windmills are the most economical prime-movers for the powers and purposes outlined in this note, and for which they are usually designed.

Appendix I.

In a "Dissertation on the Theory and Practice of Windmills," published in the *Engineering and Mining Journal*, October 7th, 1876, the writer developed the formula:

$$\tan \alpha = \frac{v}{c} + \sqrt{1 + \left(\frac{v}{c}\right)^2}$$

from which the best angle of impulse might be ascertained.

In this formula

α represents the angle of impulse of the wind upon the windmill blade (or sail), at any point of the blade, for maximum effect.

v = the velocity of the blade (at such point) in feet per second.

c = the velocity of the wind in feet per second.

The accompanying diagram (Fig. 39) is the graphical interpretation of that formula, the curves showing the best angles of impulse and "weather." The angle of "weather" is the complement of the angle of impulse, and is the angle which an element of the blade or sail makes with its plane of motion. Since there is no difference of effect between that caused by the blades moving against the air, and that caused by the air (or wind) striking upon the blades (assuming the same velocity in both cases), the angles given in the diagram will be found to be those of maximum efficiency for ventilating purposes as well as for windmills.

In the above diagram, the ordinates represent the best angles of weather and impulse, expressed in degrees, and the abscissas the ratio of the velocity of the wind to the velocity of the windmill blades. Thus, assuming the velocity of the wind to be 31.416 feet per second, the diameter of the wheel to be 35 feet, and the number of revolutions per minute to be made to equal 30, the velocity of the wind-wheel at a point $2\frac{1}{2}$ feet from the centre of the shaft will be 7.854 feet per second; at 5 feet from the centre, 15.708; at $7\frac{1}{2}$ feet, 23.562, etc., and the ratio of the velocity of the wind to the velocity of the sail $\frac{v}{c}$ will at $2\frac{1}{2}$ feet from the centre of shaft equal .25; at 5 feet, .50; at $7\frac{1}{2}$ feet .75, etc. The best angle of weather equals, therefore, at a distance $2\frac{1}{2}$ feet from the centre of the shaft, 38°; at 5 feet from the centre, 32°; at $7\frac{1}{2}$ feet, 27°, etc.; and the best angle of impulse equals, at a distance of $2\frac{1}{2}$ feet from the centre of the shaft, 52°; at 5 feet from the centre, 58°; at $7\frac{1}{2}$ feet, 63°, etc.

Appendix II.

TABLE SHOWING RELATION BETWEEN VELOCITY AND PRESSURE OF WIND.

Velocity of Wind.		Pressure of wind in pounds per square foot of plane surface, perpendicular to its course, when $P = 2116.5$ and temperature of wind =					
Miles per hour.	Feet per second.	0 F.	20° F.	40° F.	60° F.	80° F.	100° F.
1	1.46⅔	.005371	.005147	.004940	.004750	.004571	.004410
2	2.93⅓	.021482	.020586	.019761	.019001	.018294	.017641
3	4.39⅓	.048335	.046318	.044465	.042751	.041166	.039694
4	5.86⅔	.085930	.082345	.079048	.076008	.073185	.070568
5	7.33⅓	.134271	.128668	.123514	.118758	.114355	.110267
6	8.80	.193354	.185287	.177867	.171017	.164675	.158784
7	10.26⅔	.263186	.252205	.242102	.232780	.224148	.216140
8	11.73⅓	.343767	.329423	.316228	.304050	.292774	.282265
9	13.20	.436283	.416945	.400243	.384828	.370555	.357305
10	14.66⅔	.537188	.514772	.494151	.475121	.457498	.441195
11	16.13⅓	.650036	.622908	.597955	.584023	.553600	.533815
12	17.60	.773645	.741357	.711656	.684244	.658865	.635301
13	19.06⅔	.908020	.870122	.835260	.803085	.773296	.745638
14	20.53⅓	1.053106	1.010206	.968770	.931449	.896879	.864814
15	22.00	1.209087	1.158616	1.112190	1.069347	1.029670	.992841
16	23.46⅔	1.375798	1.318354	1.265523	1.216763	1.171621	1.129707
17	24.93⅓	1.553273	1.488425	1.428786	1.373721	1.322751	1.275429
18	26.40	1.741556	1.668839	1.501951	1.540180	1.483066	1.429470
19	27.86⅔	1.940634	1.859596	1.785056	1.716260	1.652571	1.593439
20	29.33⅓	2.150516	2.060705	1.978095	1.901852	1.831270	1.765740
25	36.66⅔	3.362250	3.221749	3.092521	2.973261	2.862857	2.760359
30	44.00	4.845284	4.642662	4.456311	4.284344	4.125157	3.979371
35	51.33⅓	6.600829	6.324565	6.070498	5.836055	5.619046	5.417590
40	58.66⅔	8.630351	8.268791	7.936307	7.627948	7.345581	7.082012
45	66.00	10.935522	10.476877	10.055155	9.666070	9.305975	9.971746
50	73.33⅓	13.518265	12.950585	12.428668	11.947178	11.501614	11.088085
60	88.00	19.525304	18.702993	17.947145	17.250017	16.605025	16.006591
80	117.33⅓	34.981530	33.497300	32.133920	30.877150	29.715020	28.863716

In obtaining the above data, attention was paid to the facts that the pressure depends upon both the velocity and the density of the air, and that this density depends upon the temperature, the barometric pressure, and the pressure due to the motion of the air. This table is for the average height of the barometer ($P = 2116.5$ pounds per square foot), and for any other barometric pressure the figures in the table must simply be multiplied by the ratio of the said barometric pressure, reduced to its value for temperature of air of 32° F. to 2116.5. Thus, letting p_3 = barometric pressure at any absolute temperature t, then $p = \frac{p_3 \times t}{491.4}$, and the figures in the table corresponding to wind pressure must be multiplied by $\frac{p}{2116.5}$.

For details of the method by which the above table of pressures is obtained, see *Engineering and Mining Journal*, September 23d, 1876.

Discussion.

Mr. Root: I am glad to see this subject come up. I think in the future it will have a great deal of importance. The suggestion has been made to procure power by connecting windmills with electric wires, and also by compressing air into pipes and connecting mills together over a large tract of country, whereby the loss from calms would be in a great measure neutralized, the wind probably blowing in one place while it was calm in another. It would only be a question of covering sufficient territory, to secure constant power. I think that in the future this subject will receive a great deal of attention, and that the winds will be found to be one of the most valuable sources of power. I think it deserves a far larger share of the attention of engineers than it has received.

Mr. Strong: This subject of windmills is one to which I have given some little time. I spent three or four years in experimenting on the construction and operation of windmills for farm and railroad pumping, and I think Mr. Wolff's tables are very moderate in their estimate of power. In regard to the operation of railroad water stations, the first cost of a railroad water station with steam-power and sufficient tankage is in the neighborhood of two thousand dollars. The actual expense of running a water station of that kind is an engineer at a dollar and a half a day, which would amount to forty-five dollars a month, and about twelve to fourteen tons of coal a month, the whole cost amounting to the neighborhood of two thousand dollars for the operation of a single station. The first cost of putting up a water station, with sufficient tankage for using windmills, which require about three times the amount of tankage that steam-pumps require, is about twenty-five hundred dollars, nearly the same as the steam water station. As to attendance, one man on a line of road is able to attend to all the mills on that line. Now, I have seen places where the windmill is adopted. At one place on the Camden and Amboy road, where they kept a man constantly at work pumping for the small stations, we put a pumping station on, with a windmill with the same amount of tankage. It was near the coast, and the wind was very regular, and although they used the full amount of the tank every day, they were never out of water. Last summer I was in London, and Sir William Thomson read a paper before

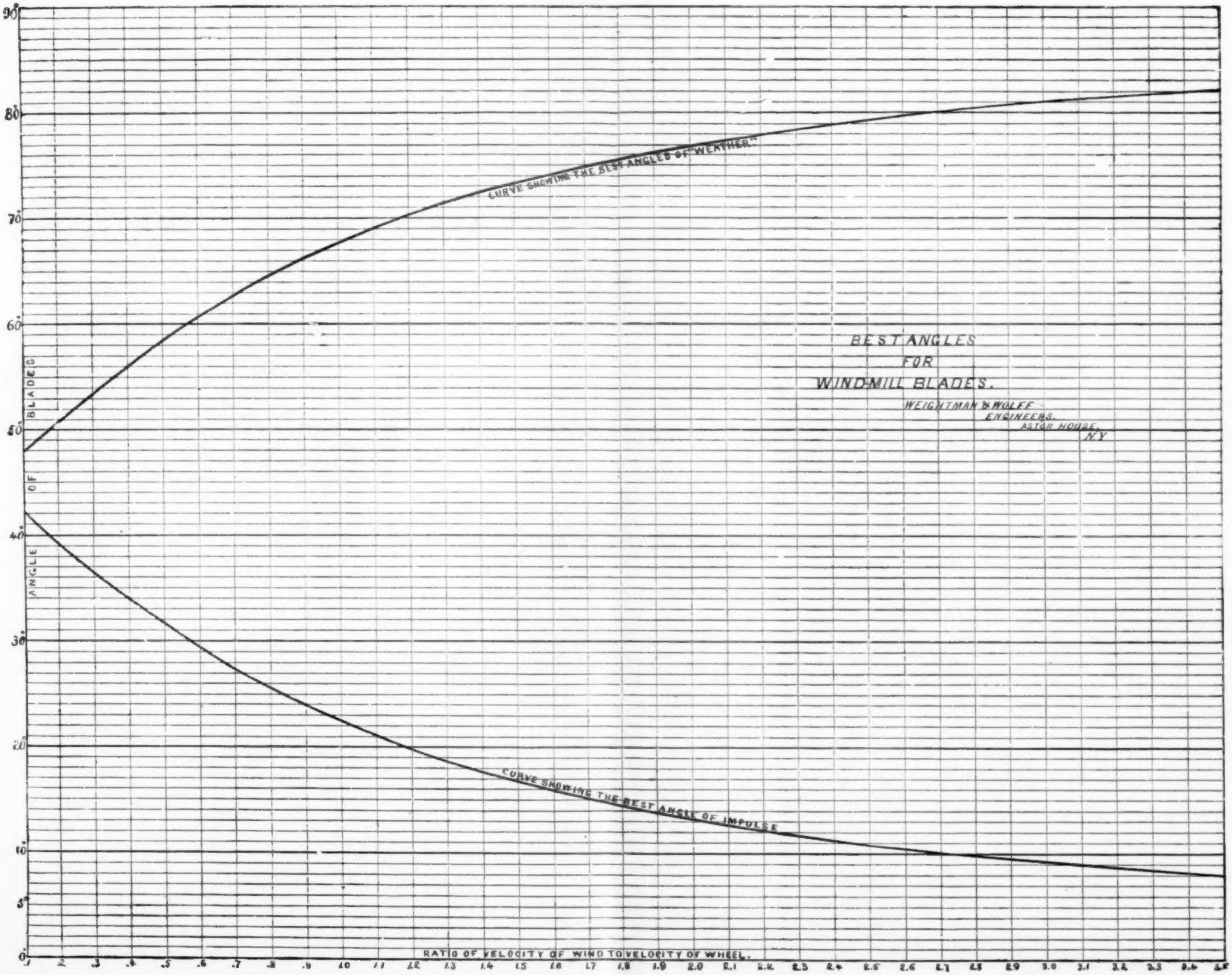

BEST ANGLES
FOR
WIND-MILL BLADES.
WEIGHTMAN & WOLFF
ENGINEERS.
ASTOR HOUSE.
N.Y.
CURVE SHOWING THE BEST ANGLES OF "WEATHER"
CURVE SHOWING THE BEST ANGLE OF IMPULSE
ANGLE OF BLADES
RATIO OF VELOCITY OF WIND TO VELOCITY OF WHEEL.

Fig. 39.

the British Association, in which he remarked that he was sorry this question of windmills had not received more attention from engineers, and that he did not know, or did not think, that a practical windmill had ever been invented. The report was published in the London *Times*, and I wrote to Sir William Thomson that I had made some experiments, and I should be pleased to give him any information that I was able to furnish. He wrote me in reply, that he would be pleased to meet me in London the following day. I had quite a talk with him on the subject. I told him the experience I had had, and he was very much surprised to know that Americans had gone so far with windmills as they had, there being, practically, nothing done in this direction on the other side, the old fashioned mill being used all over Europe, and very extensively in the north of England, not only for pumping, but for grinding. I venture to say that one-half of the flour used throughout Europe is ground to-day on those old-fashioned mills. I also had a conversation with Mr. Brush, of the Brush Electric Light Company, in Cleveland, not long ago. Mr. Brush had given this subject his attention, and, in connection with accumulators of electricity with which he is experimenting, he thinks it is quite practicable to adapt the windmill to the storage of electricity, and make it a very effective prime-mover.

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